ATMOSPHERIC DIFFUSION STUDIES AT THE NARF SITE

by

H. G. Bradbury
General Dynamics/Fort Worth, Fort Worth, Texas
(NARF)
Contract AF 29(601)-6213

TECHNICAL REPORT NO. WL TR-64-156

Research and Technology Division
AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base
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FOREWORD

The work reported in this document was performed at the Nuclear Aerospace Research Facility, General Dynamics/Fort Worth, under Air Force Contract AF 29(601)-6213, Project 6773, Task 677305, Program Element 6. 54.02.12.4. The document was submitted 29 April 1965 in accordance with Item 34 of the statement of work (FZM-2959-A) covering the period 1 October 1963 through 30 September 1964.

The Air Force Project Monitors were Major R. R. Stewart, AFWL (WLDA-2), and Mr. A. J. Smith, AFWL (WLAS). The author was assisted in the design, setup, and operation of the test equipment by Dr. R. E. Fields and W. A. Baird.

The contractor's report number is FZK-206.

This technical report has been revieved and is approved.

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ABSTRACT

Four atmospheric diffusion experiments were conducted in the Nuclear Aerospace Research Facility area at General Dynamics/Fort Worth in order to study the dispersal and dilution factors of the atmosphere as they pertain to the release of airborne radioactivity in the NARF area. Fluorescent dye was released to the atmosphere from a point near the Reactor Operations Building and sampled downwind to measure depletion factors under varying meteorological conditions. The tests were performed with air temperature gradients ranging from slightly unstable to mildly stable (inversion) situations. The sampling data obtained were applied in the evaluation of the parameters associated with the statistical diffusion equation. Although the four tests were too few in number to provide substantial statistical data, the results show that under the poorest diffusion conditions experienced, the effluent depletion factors ranged from approximately 10^{-4} to 10^{-6} between 88 and 704 m from the release point. These factors are considerably less than those actually being applied under nuclear safety considerations within the NARF reactor operations area.

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1. INTRODUCTION

The purpose of the diffusion tests described in this report was to study the dispersal and dilution factors of the atmosphere as they pertain to the release of airborne radioactivity from the Aerospace Systems Test Reactor (ASTR) and the Ground Test Reactor (GTR) at the Nuclear Aerospace Research Facility (NARF). The tests consisted of the releasing of uranine dye under different meteorological conditions. The dye, simulating radioactive aerosols, was sampled downwind and assayed so that diffusion parameters could be evaluated for all probable conditions of release of radioactive aerosol to the atmosphere. The tests were performed during January, February, and March of 1964.

1.1 Need for Diffusion Tests

Associated with every nuclear reactor facility is the problem of evaluating and monitoring the airborne radioactivity that may result during normal operations and/or during certain conceivable accident situations. Extensive work, both analytical and experimental, has been done under previous NARF contracts to develop more adequate methods and input data for coping with the atmospheric diffusion aspects of this problem in relation to airborne nuclear vehicles (Refs. 1-8). The impetus for this study is the need for

knowledge concerning atmospheric diffusion parameters as they relate specifically to the NARF area at General Dynamics/ Fort Worth (GD/FW).

In the interest of nuclear safety, operation of the nuclear reactors at this location is carried on under certain restraints imposed by essentially theoretical models of atmospheric diffusion. It is the author's thesis that the assumptions are highly conservative with respect to hazardous pollution of the environmental atmosphere by radioactive contaminant. As a consequence, the restrictions that are being imposed increase the cost of operations, limit some of the operations, and may, in some instances, be unnecessary. However, without experimental information relative to the diffusivity of the atmosphere in the NARF area, the assumption must continue to guide reactor operations in order to ensure nuclear safety within the environs of NARF.

1.2 Diffusion-Test Background Information

A portion of the experimental work reported here has been done at various remote sites - National Reactor Testing Station, Dugway Proving Ground, Nevada Test Site - where large-scale experiments have been performed. Data from these experiments have been analyzed along with similar data from experiments of others, e.g., the Stanford releases at Dugway and the Air Force Cambridge Research Center's "Project Prairie Grass" in

Nebraska (Refs. 1, 5-12). Much use has been made also of the more general literature of micrometeorology and atmospheric diffusion (Refs. 13-24). Results thus obtained have been applied to the general evaluation of the similar problems associated with the nuclear reactors at NARF.

However, since none of the experimental work cited had been done at the NARF site, the results were never entirely applicable to NARF, where it is necessary not only to predict hazards of conceivable nuclear accidents but also to monitor continuously the atmospheric activation during some operations and calculate concentrations both on and off the site. Hence, as early as 1960 it was decided that diffusion tests employing a nonradioactive aerosol should be undertaken locally to provide more definitive data specifically for the NARF area. These tests, begun in late 1960 and extending into the Spring of 1961, were discontinued when the ANP program was canceled. Meanwhile, the need for such tests continued to increase because of the subsequent increase of the ASTR power level and enlargement of irradiation cells used with both the ASTR and the GTR. To comply with the requirements placed on NARF by the Air Force Directorate of Nuclear Safety (DNS) and the Nuclear Reactor Systems Safety Group (NRSSG) for monitoring release of radioactive argon, the test program described here was undertaken.

1.3 Character of Diffusion Data Needed

Release of particular radioactive materials into the atmosphere is a normal result of operation of the NARF nuclear reactors. Furthermore, certain types of accidents could conceivably result in release to the atmosphere of other radioactive materials. Therefore, a necessary part of the facility safety assurance program is (1) the maintenance of adequate monitoring of airborne radioactivity during normal operation and (2) the provision, in advance, of suitable measurements and calculations to allow immediate estimation of airborne radioactivity distribution in the event of an accident.

Some of the needed data on atmospheric diffusion at NARF were obtained through previous experimentation. This work, begun several years ago at the suggestion of the DNS, was never completed because sufficient funds were not available. Preliminary measurements of diffusion were made with a fluorescent tracer aerosol emitted at the ASTR stack and sampled at the exclusion area fence during near-neutral atmospheric stability conditions. In the present work, a greater number of sampling stations covering a larger area made it possible to obtain a more complete picture of the effluent distribution from the reactor stacks.

In April 1961, a few isolated tests were conducted that employed uranine dye as a release simulant to measure dilution

downwind. The releases were made under near-neutral lapse conditions and none was conducted under strong lapse or inversion situations. The data thus obtained are so restrictive that it is neither possible to arrive at the parametric evaluations needed to predict or ascertain the degree of hazard generated by a nuclear incident nor feasible to predict or ascertain the dilution of radioactive gases released during normal routine reactor operations. In consideration of environmental (public) safety under AEC standards, there follows the need for evaluation of diffusion parameters as concerns the NARF area.

2. THEORETICAL CONSIDERATIONS FOR DIFFUSION TEST PLAN

In order to evaluate the diffusive qualities of the atmosphere above a given locality, it is necessary to study the smaller-scale meso- and micro-meteorological elements peculiar to the region. The most important of these are the local wind movements and the air stability, or vertical gradient of air density (or temperature), within the lower few hundred feet of the atmosphere. The diffusive capacity of an air mass is strongly influenced by its vertical thermal structure. When the temperature of the air is plotted as a function of height above surface, the curve is conveniently referred to as a temperature profile.

2.1 Lapse Rate and Atmospheric Stability

At a given pressure and fixed volume, the temperature of a gas is inversely related to density, and its acceleration, due to buoyancy force, is proportional to the difference between its density and that of the medium in which it is submerged. Buoyancy alone is not sufficient to account for the motions which actually occur, but the temperature profile, together with its associated buoyancy effects, is a necessary consideration when an estimate is made of the concentrations of airborne material (e.g., radioactive effluents) downwind from a source.

The rate of decrease with elevation in the value of any meteorological element is usually referred to as its lapse

rate. With a normal or standard lapse rate (e.g., U. S. Standard Atmosphere), the rate that temperature decreases with height is specified as $3.5^{\circ}F/1000$ ft (or $0.65^{\circ}C/100$ m).

If the lapse rate is such that it shows no change of temperature with height, it is isothermal. A stratum with an "inverted" (or positive) gradient, in which the temperature increases with elevation, is designated as an inversion (Fig. 1).

Of particular interest in diffusion study is the unique atmospheric lapse rate which permits a parcel of air to be displaced from one level to another so that the parcel always has the same density as its environment (assuming that unsaturated air and temperature changes within the parcel take place without an exchange of heat with its surroundings). Since a change of state (i.e., of temperature, pressure, and density) of a gas is said to be adiabatic if it takes place without heat being supplied or withdrawn, the lapse rate referred to is known as the dry adiabatic lapse rate or sometimes as just the adiabatic rate. Numerically, it is equal to a decrease with elevation of $5.4^{\circ}F/1000$ ft (or $1^{\circ}C/100$ m).

2.2 Atmospheric Stability and Effluent Behavior

When the lapse rate is more than the adiabatic, all vertical motions are accelerated, so that the atmosphere is said to be unstable. On the other hand, if a lapse rate

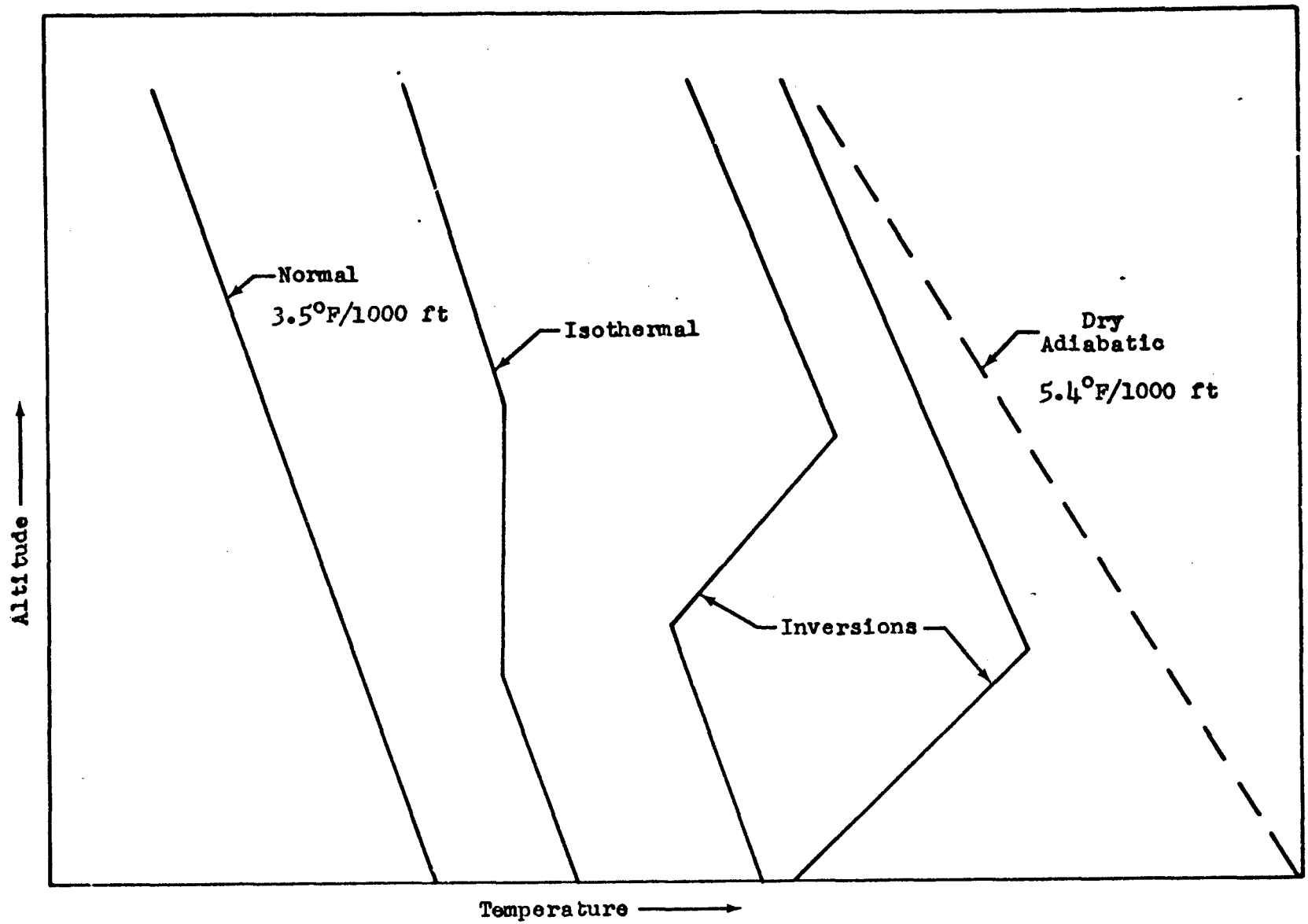

Figure 1 Temperature Profiles Illustrating the Normal Lapse Rate, an Isothermal Lapse Rate, and Inversions

is less than dry adiabatic, a parcel of air displaced upward will have a temperature that is lower than its surroundings or, if displaced downward, a temperature that is higher. In this case, buoyancy forces tend to restore the parcel to its original level, so that the atmosphere is said to be stable. If the lapse rate is exactly dry adiabatic, the air is neither stable nor unstable, so that conditions are said to be neutral. The effect of air temperature lapse rate on the diffusion of aerosol-type contaminants in the atmosphere is that, in general, a "lapse" condition (positive lapse rate) enhances diffusion while an inversion (negative lapse rate) produces poor diffusion.

The effects of various conditions of vertical temperature stratification are represented in Figure 2. The types of stability are divided into five classes. Since the atmosphere is a hydrodynamic system, none of the types is ever entirely static. Changes occur because of changes in air mass on the micrometeorological scale. In a 24-hr period, the temperature profile can change from a superadiabatic lapse rate in the afternoon to a strong nocturnal inversion between midnight and sunrise. Although temperature profiles in Figure 2 are shown as straight lines, this is not the usual case, since lapse rate is a complex nonlinear function, with the greatest deviation from linearity occurring near the ground. Therefore,

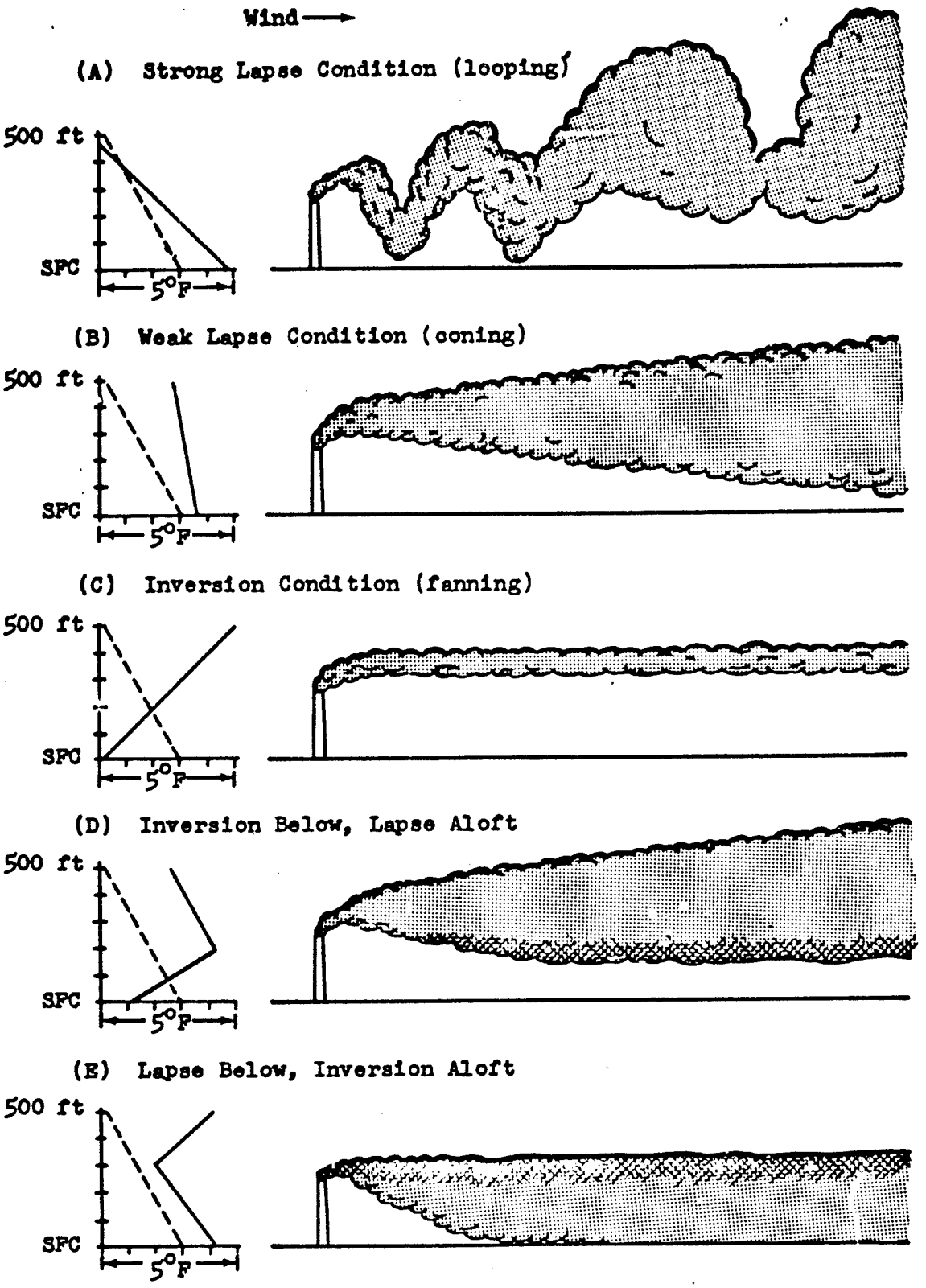

Figure 2 Schematic Representation of Stack-Gas Behavior under Various Conditions of Vertical Stability

several points of temperature measurement are required below 100 m to properly describe the vertical gradient in the lowest layer of the atmosphere. A description of smoke behavior to be expected with each type is given below.

Type A: Looping. Looping occurs with superadiabatic (very unstable) lapse rate. The stack effluent appears to loop because of thermal eddies in the wind flow. Gases diffuse rapidly, but sporadic puffs having strong concentrations are brought to the ground very near the base of the stack for periods of a few seconds.

Type B: Coning. This type of plume occurs with a gradient lying between dry adiabatic and isothermal. The effluent stream is shaped like a cone with axis horizontal. The distance at which effluent from the stack first comes to the ground is greater than that of Type A, because thermal turbulence and, hence, vertical motions are less.

Type C: Fanning. Fanning occurs with temperature inversion (stable) conditions. Laminar flow may also occur in a layer of air that is isothermal, depending on wind speed and roughness of terrain. The stack effluent does not diffuse in the vertical. The effluent trail may resemble a meandering river, widening very gradually with distance. Depending on the duration of the stable period and the wind speed at stack level, the effluent may travel for many miles with little dilution occurring in the effluent stream. The concentration

within the stream varies inversely with wind speed, but the distance that the effluent travels within a given time interval is directly proportional to wind speed. Calm or very light and variable winds at the effluent level are most frequently found with this type. Under such circumstances, the effluent is most concentrated in the vicinity of the stack.

Type D: Lofting. This type of plume occurs with the transition from lapse to inversion, so that it is likely to be observable most often near sunset. Depending upon the height of the stack and the rate of deepening of the inversion layer, the lofting condition may be very transitory or may persist for several hours. The zone of strong effluent concentration, as shown in Figure 2(D), will depend on the height of the inversion. The inversion causes trapping of the effluent carried into the stable layer by turbulent eddies that penetrate the layer for a short distance. Except when the top of the inversion is very near the ground, this type may be considered as the most favorable situation to be encountered. The inversion prevents effluent from reaching the ground and, at the same time, the effluent may be rapidly diluted in the lapse layer above the inversion.

Type E: Fumigation. This condition occurs at the time that the nocturnal inversion is being dissipated by heat from the morning sun. The lapse layer usually begins at the ground and works its way upward — rapidly in summer but slowly in

winter. At some time, the inversion is just above the top of the stack and, acting as a lid, forces the effluent stream to dilute within the shallow lapse layer near the ground. Large concentrations are brought to the ground along the entire effluent stream (which may be quite long because of previous fanning conditions) by thermal eddies in the lapse layer. Fumigation causes strong effluent concentrations to be brought to the ground, at least briefly, at great distances from the stack, and it results in stronger sustained ground concentrations near the stack than looping, coning, etc. The duration of fumigation depends upon the rate of deepening of the lapse layer as the nocturnal inversion dissipates and upon the height of the stack. In some places, inversion lids are known to persist for several days. Fumigation conditions may persist for prolonged periods in deep layers of radiation fog; this situation, for instance, is the type that produces smog in the Los Angeles Basin.

The effects of various lapse rates on effluents generated in the NARF area are demonstrated in a series of smoke releases shown in Figures 3 through 10. Smoke releases under lapse conditions from the GTR stack and an oil fire are shown in Figures 3 through 5. Effluents studied near the meteorological tower are shown in Figures 6 through 8. The effects of an inversion on the diffusion of smoke from hot oil fires are exhibited in Figures 9 and 10.

Figure 3. Smoke Released Under Lapse Conditions from Stack of Ground Test Reactor with Blower On

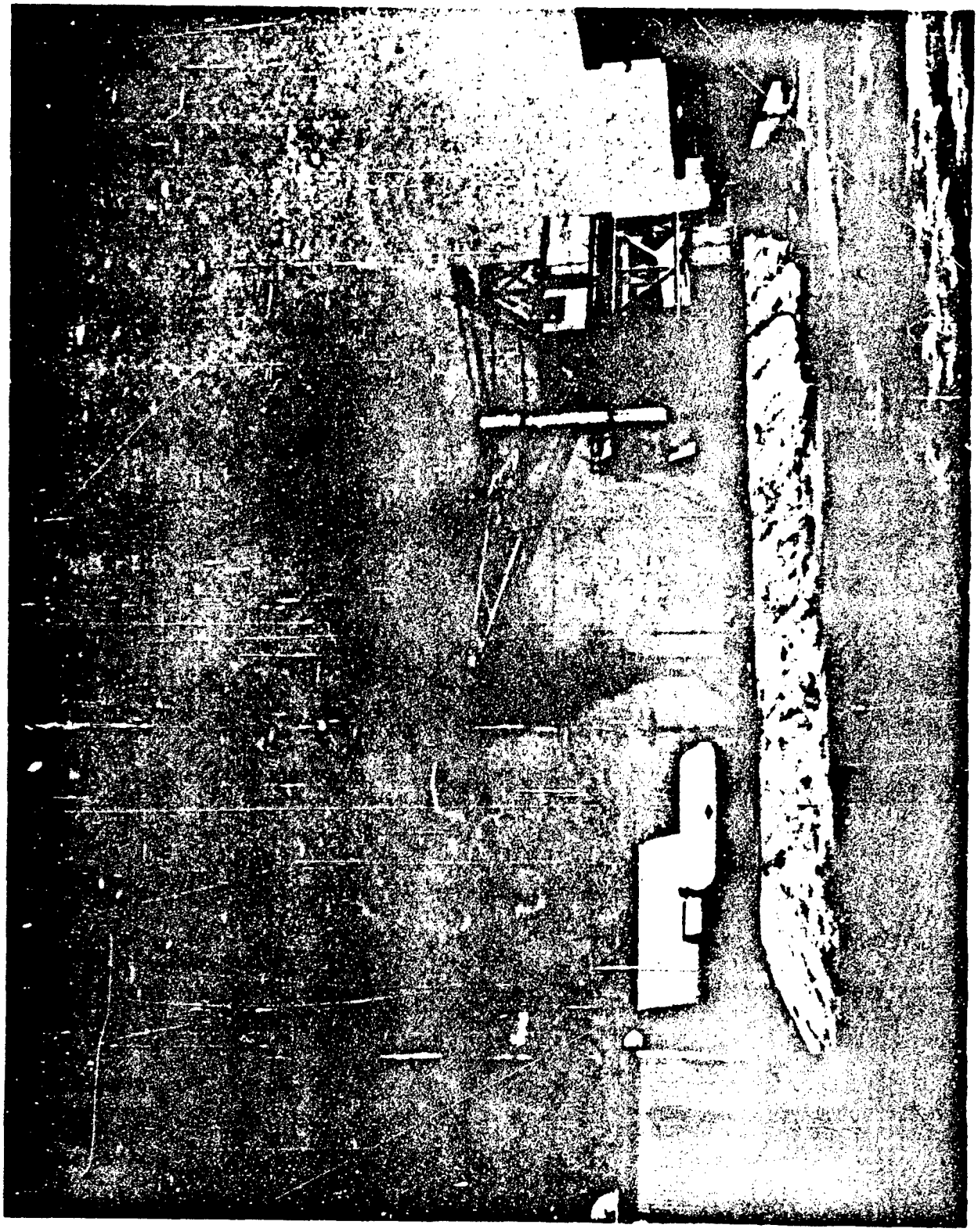

Figure 4. Smoke Released under Lapse Conditions from Stack of Ground Test Reactor with Blower Off

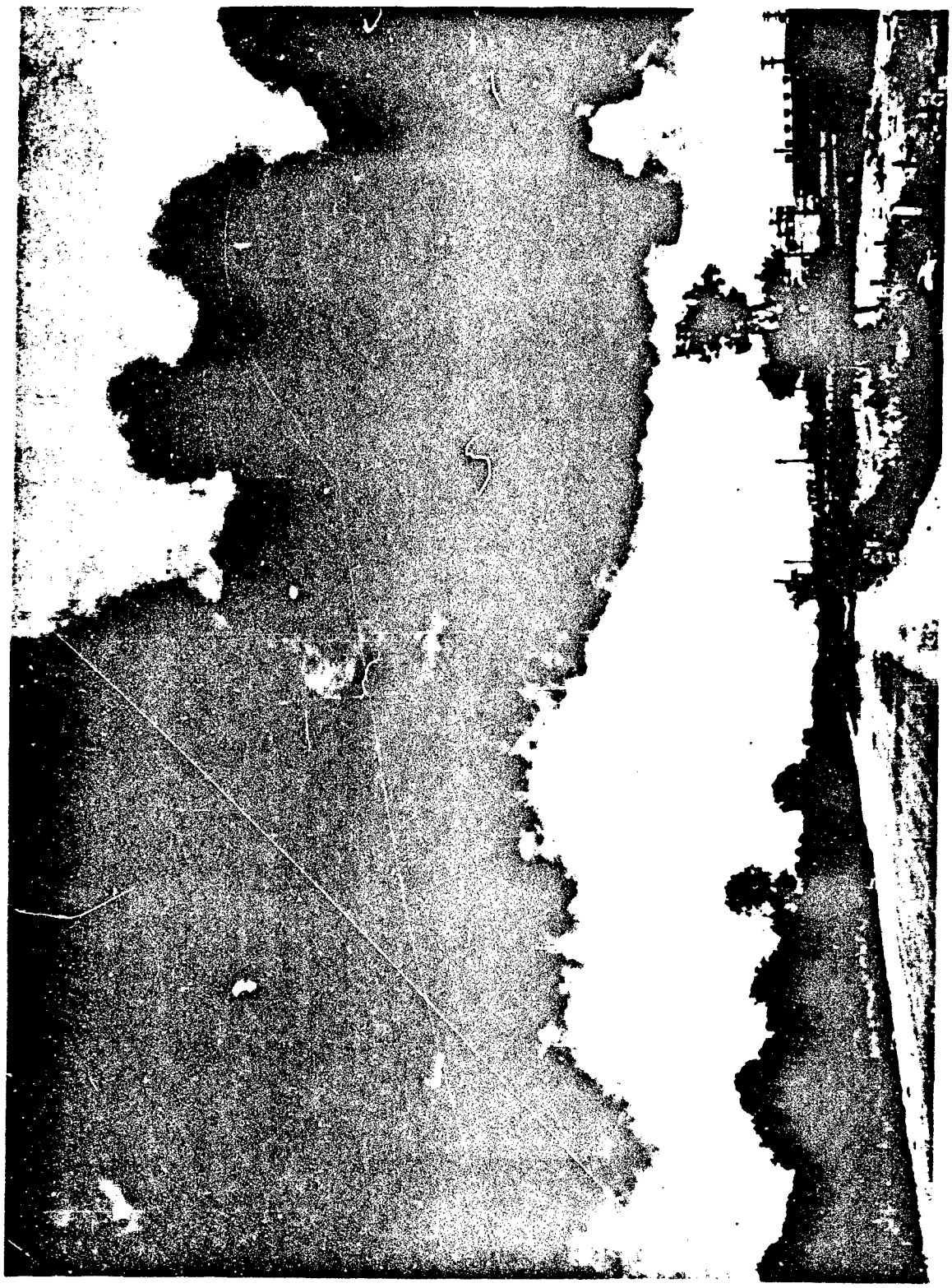

Figure 5. Sampling Smoke from Waste-Oil Fire under Lapse Conditions

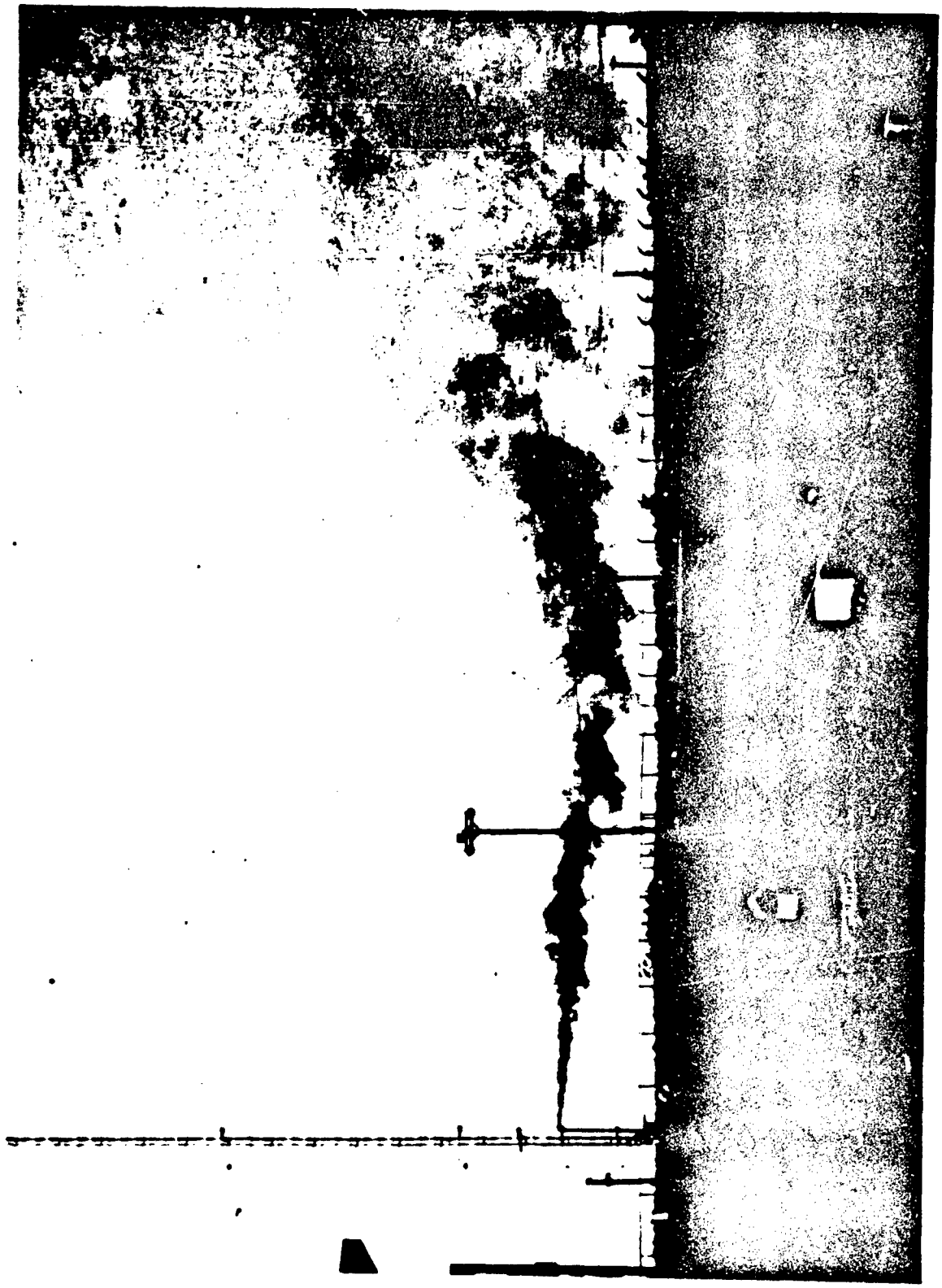

Figure 6. Coning of Smoke Released under Mild Lapse Conditions

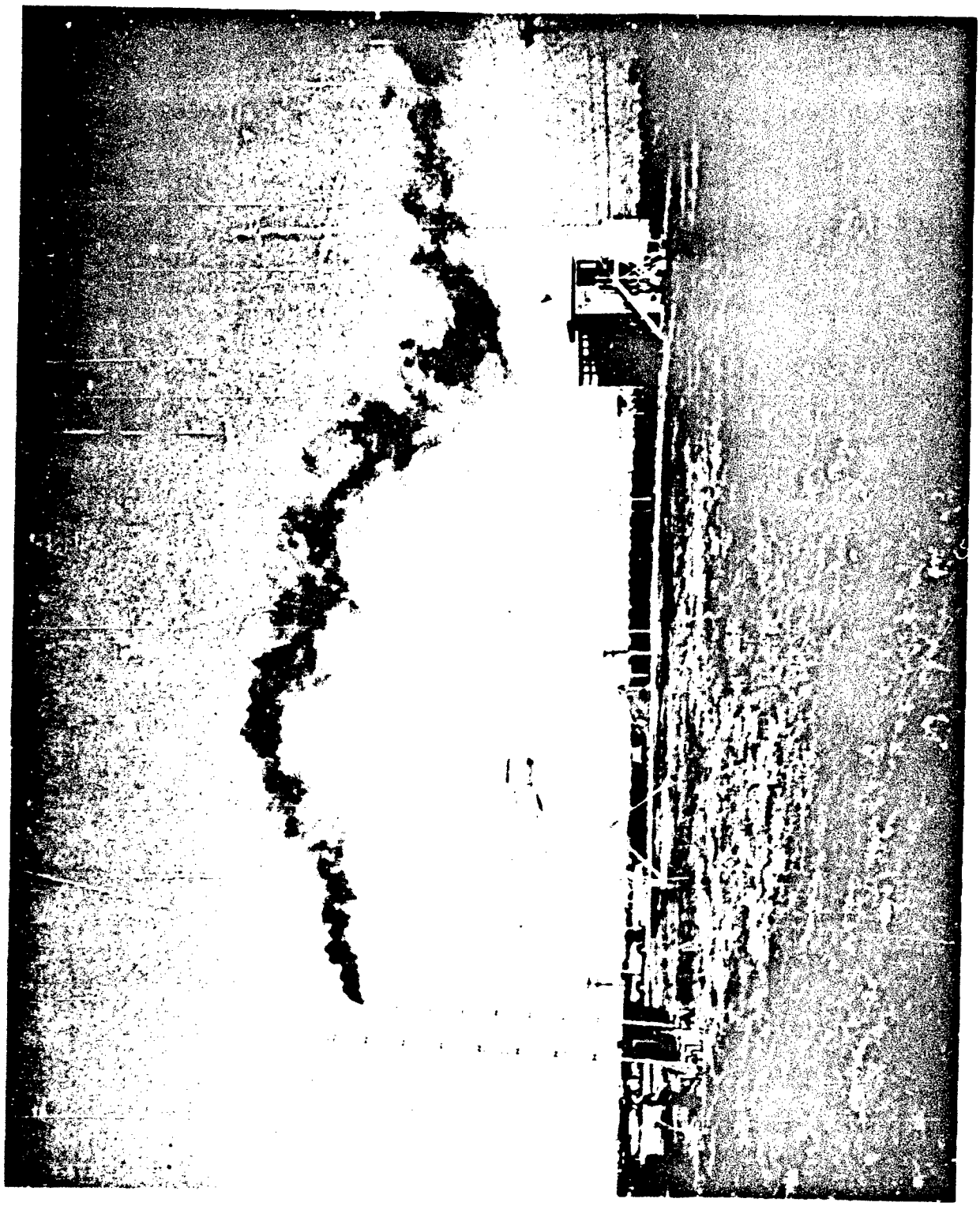

Figure 7. Looping of Smoke Released under Normal Lapse Conditions

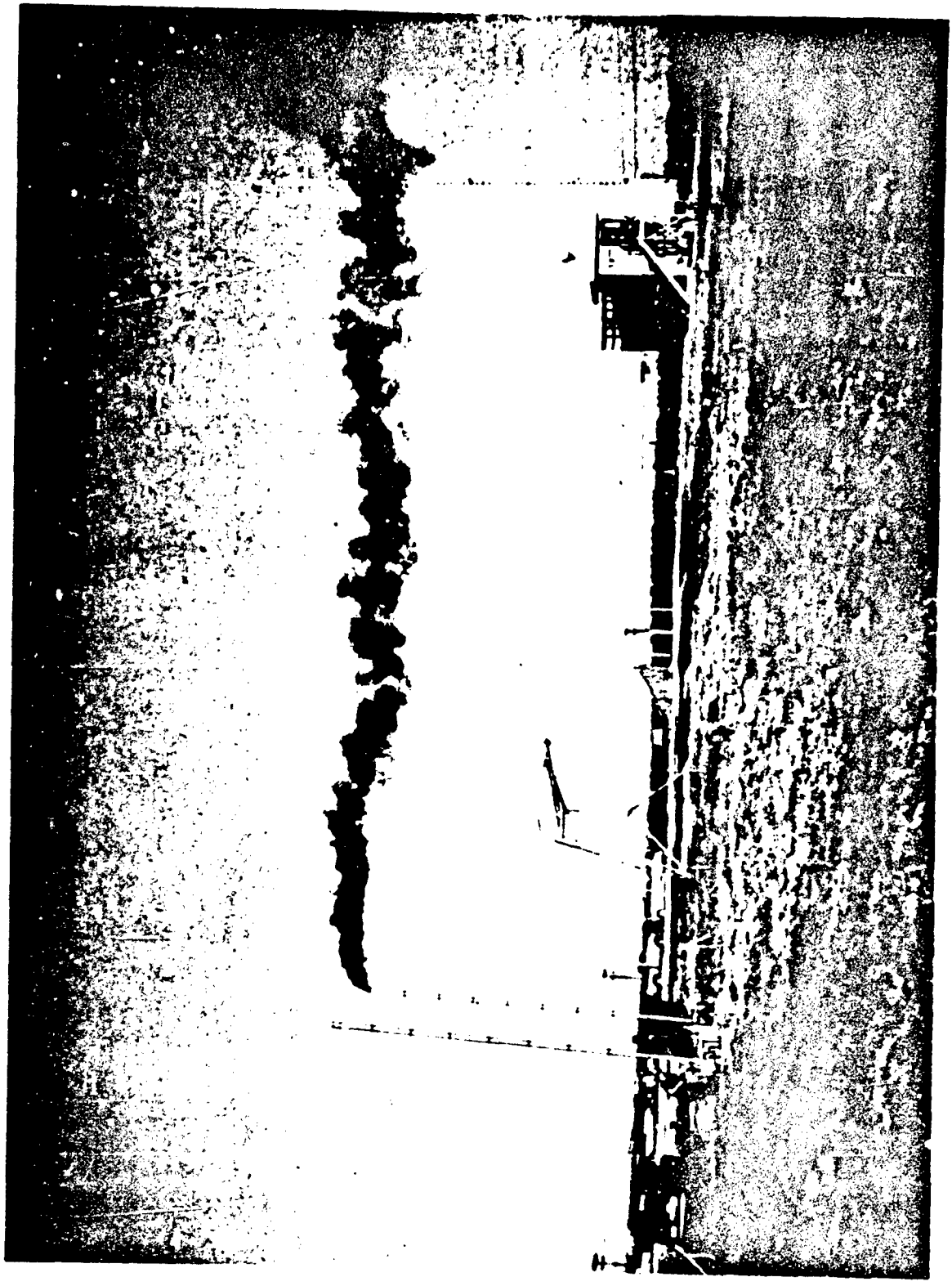

Figure 8. Smoke Released under Approaching Neutral Conditions with Solid Carbon Dioxide Used to Cool the Effluent

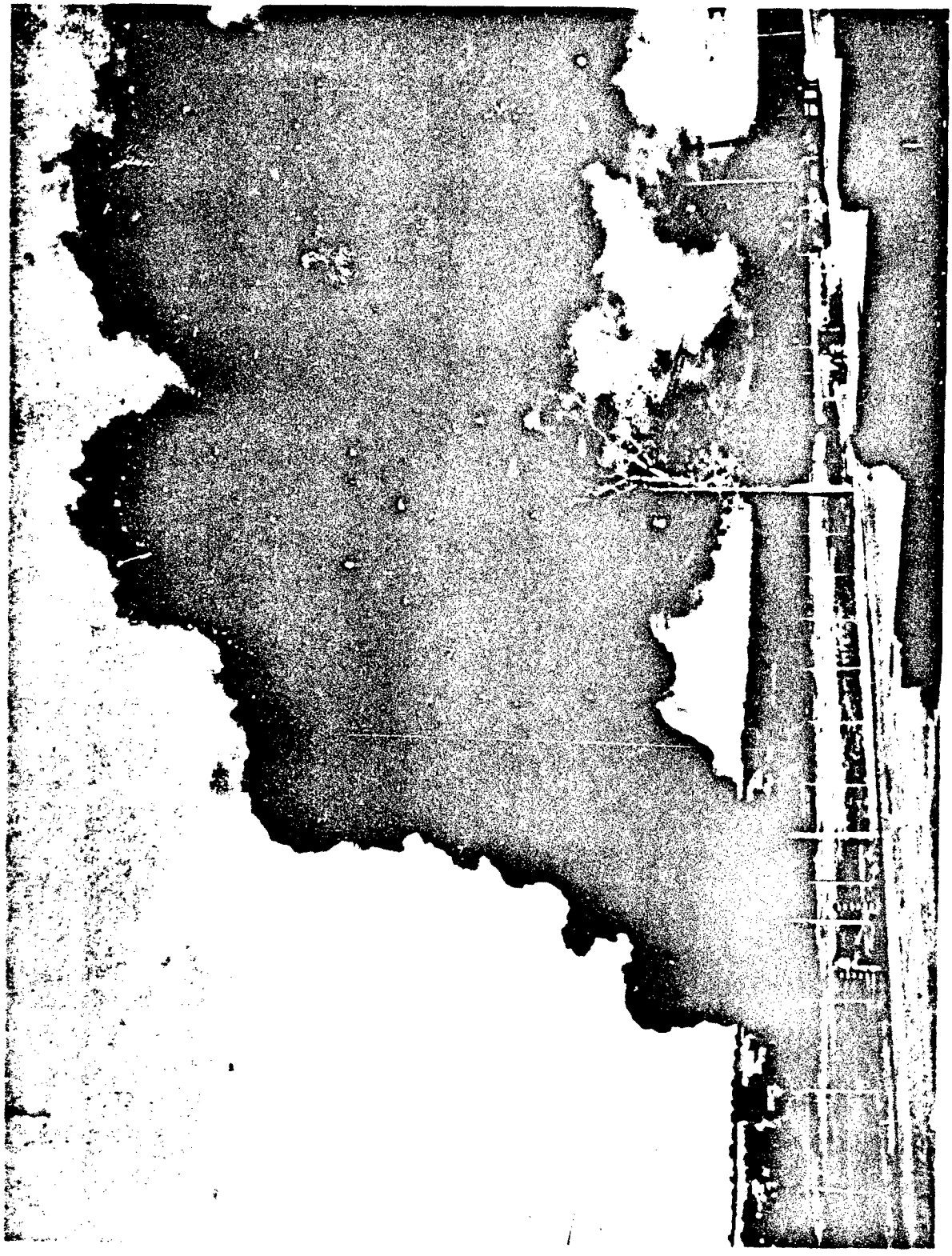

Figure 9. Fumigation Demonstration Using Oil-Fire Smoke During Temperature Inversion Aloft and Temperature Lapse Below

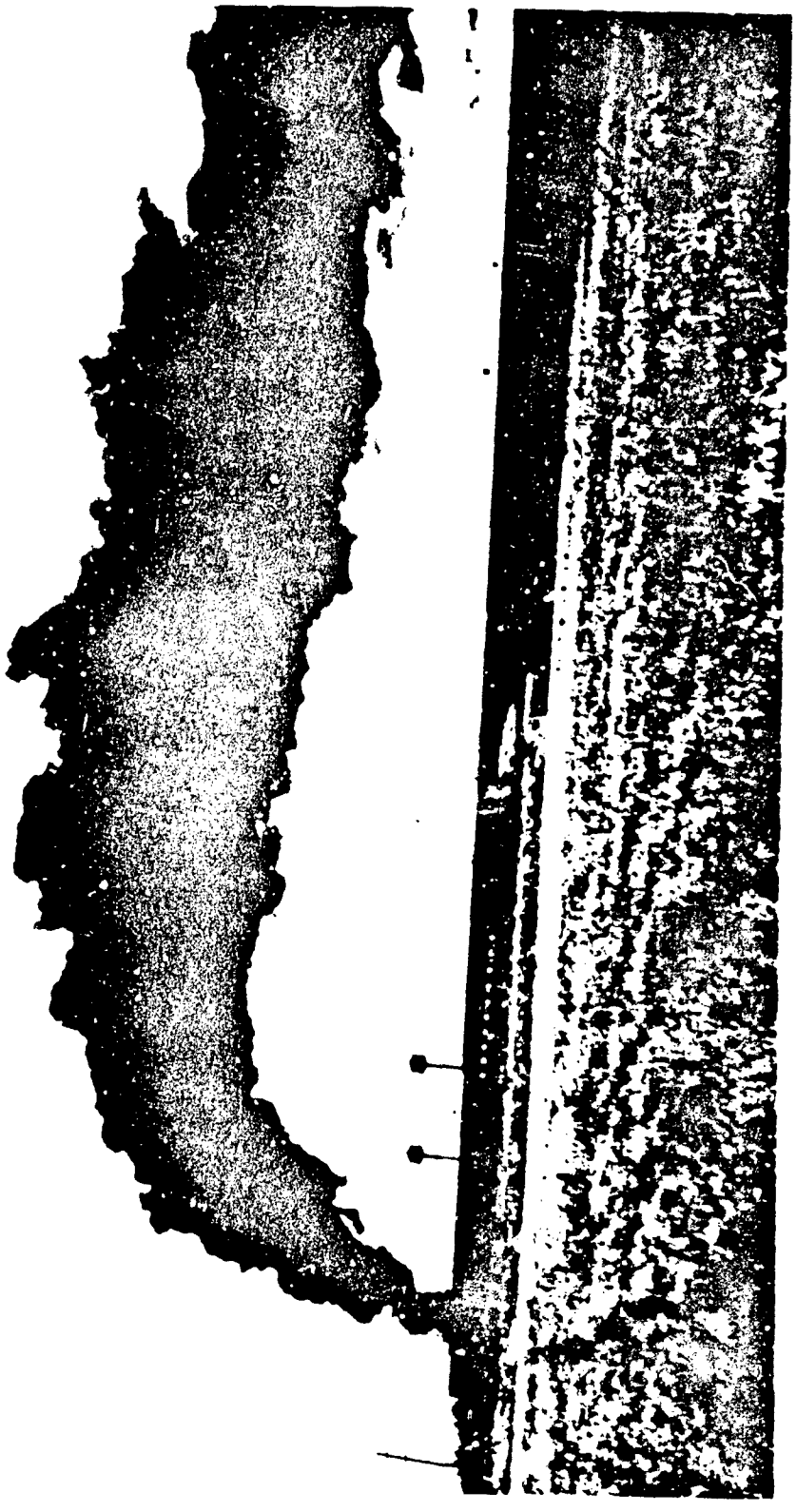

Figure 10. Oil-Fire Smoke Fanning under an Inversion Condition

Clearly then, it follows that the extent of hazard resulting from release of radioactive aerosol to the atmosphere is greatly dependent upon the thermal gradient occurring in the air during the event. Factors which control or determine the lapse rate are net heat exchange (air-ground), air-mass movement, air turbulence (gustiness), wind-direction variation, topography, buildings, and type of radioactive surface. These factors vary from one locale to another and, as a consequence, an evaluation of the diffusion parameters for a given location must of necessity be accomplished through diffusion experiments conducted in that particular area.

2.3 The Statistical Diffusion Equation

Diffusion parameters have been fitted to numerous field release tests by the statistical method presented in the generalized form of the atmospheric diffusion equation suggested by F. P. Leonard (Ref. 12). This method has produced agreement in parameter values between different diffusion experiments. The method involves fitting an equation of the form

$$\chi(x,y,z) = \frac{Q(x)}{2\pi\sigma_y\sigma_z}\left[\exp\left(-\frac{(h+z)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(h-z)^2}{2\sigma_z^2}\right)\right] e^{-\frac{y^2}{2\sigma_y^2}}$$

where

$\chi(x,y,z)$ is the air concentration of material at x, y, z (gm-sec/m^3);

$Q(x)$, the time integral of material released per meter of effluent cloud (gm-sec/m) and is equal to $\frac{Q}{\bar{u}}$;

$\bar{u}$, the mean wind velocity; and

h, the release height.

The horizontal and vertical standard deviations are

$$\sigma_y \equiv \frac{1}{\sqrt{2}} \; C_y \, x^{m_y} \qquad \text{and} \qquad \sigma_z = \frac{1}{\sqrt{2}} \; C_z \, x^{m_z}$$

C_y, C_z, m_y, and m_z are the diffusion parameters. Evaluation of these constants may be obtained by "fitting" experimental release test data. Arc profiles are fitted in the manner described by J. C. Couchman (Ref. 3). The diffusion equation and the curve-fit parameters are used to predict the maximums and the crosswind areas. This method makes it possible to fit parameters to the results of a field release, regardless of how skewed or scattered the arc distribution may be, and thereby eliminate the bias that might be introduced by preferential selection of the better arc profiles. Should the airborne material be radioactive, the cloud must be depleted by a radiation decay factor.

The statistical diffusion equation is a semiempirical equation relating a Gaussian distribution to measured values of source, arc-sample concentrations, source distribution over an area, and meteorological variables. These values are to be obtained through atmospheric diffusion experiments. In consideration of the many factors involved in the dispersal and dilution of airborne pollutants, it follows that many such

experiments or tests are required in order to predict or assess the hazard that results from the release of radioactivity to the atmosphere.

3. DIFFUSION TEST PLAN

A general description of the plan for the NARF diffusion studies is given below. The Operations Plan, including areas of responsibilities, project assignments, and the test event timetable, is given in Appendix A.

The Operations Plan called for at least nine tests. Three were to be run under mildly stable conditions, three under highly stable conditions, and three under conditions varying from slightly stable to highly unstable, the latter being intended for correlation with the previous series accomplished in 1961. However, because the various weather conditions specified by the Operations Plan failed to materialize during the test period, only four tests were performed. Of these four, one test was run under mildly stable conditions and three were run under mildly unstable conditions. Testing involved four phases, in accordance with provisions of the Operations Plan.

3.1 Phase 1: Aerosol Generation

The aerosol generator (paint spray gun) was loaded with a suitable solution of uranine dye in water and set up near the ASTR pit exhaust stack. Previous use of this device has shown that it produces a fine aqueous spray and that upon evaporation of the water surrounding the uranine nuclei, an

aerosol is formed. The urznine particles that result are small enough to constitute a true aerosol, mainly in the range of from 0.5 to 1C.0 microns.

3.2 Phase 2: Sampling Array

Approximately 30 aerosol samplers fitted with molecular membrane-type filters were set up to take samples 1.5 m above ground along each of four arcs concentric about the aerosol release point and with radii of 88, 176, 352, and 704 m. These samplers ran continuously during the passage of the fluorescent effluent cloud. The type of sampler used was the Gelman Bantam, with 0.6-cfm air flow-rate capacity. The unit operates on 110 v-ac, weighs 8 lb, has dimensions of 9 x 5 x 4.5 in., and is supplied with a 2-in. open (filter) holder. The holder was mounted near the top of a 5-ft stanchion and connected to the sampler pumping unit by means of latex tubing. The sampling unit was placed on the base of the portable stanchion, consisting of a 5-ft-long, 1-in.-diam pipe held in a vertical position by a solid (concrete) cylinder. Four 25-ft stanchions were positioned on the 704-m arc to permit sampling above the roofline of an intervening structure. Electric power was supplied each unit through a cable placed on the ground (or concrete surface) along four concentric arcs subtending an angle of 60° and having their center near the ASTR exhaust stack. The electric power distribution network was

portable to accommodate traffic, periods of non-testing, and variation in orientation of the sampling array. Receptacles (110-v outlet) were provided at each sampling station. The Bantam motor draws 2 amp of current.

In addition to the 121 electrical outlets distributed along the four arcs, six receptacles were provided on each of the 88- and 176-m arcs to supply power to 12 more Bantam units used with Casella and Andersen impactor-type samplers.

Master switches were provided for the arcs for the purpose of conveniently controlled "on-off" electric power.

3.3 Phase 3: Assay of Samples

Following an aerosol (uranine) release, the holders containing the filter (sample) were removed from the standard and taken to the laboratory for analysis. The uranine, being water-soluble, was removed from the filter by washing in distilled water. The resulting water solution was assayed with a fluorometer to determine the amount of uranine collected by the filter.

The samples obtained by the impactors were examined under a microscope for the particle-size study of the collected aerosol. The uranine was removed from the sample plates by dissolving in an alcohol-water mixture and was assayed with the fluorometer.

3.4 Phase 4: Analysis and Results

Isopleths of uranine concentration in the air were plotted to show graphically the distribution of fluorescent aerosol downwind of the release point. From these data, dilution factors were computed and correlated with meteorological conditions (wind speed, wind variability, temperature, lapse rate, humidity, air stability from bivane data, and net radiation) obtained from the Atmospheric Physics Facility.

Plans calling for the participation of an Air Weather Service team in the diffusion tests were canceled because of a conflict in the test schedule and the project commitments of the team. This team, under the surveillance of AFWL, was to make meteorological measurements independent of the above-described sampling array and meteorological measurements.

The original schedule of events for the diffusion tests is given in Table 1.

Table 1

NARF DIFFUSION TEST SCHEDULE

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Aerosol Generation		xxxx		xx	x	x						
Sampling Array												
Planning	xxxx											
Setup		xxxx	x	x	x	x						
Operation				x	x	x						
Assay of Samples				x	x	x						
Analysis and Results			x	x	x	x	x					x
Report	x	x	x	x	x	x	x	x	x	x	x	xxxx

4. TEST OPERATIONS AND RESULTS

4.1 Operations Activities

During the first quarter of the NARF-64 period, activities pertaining to the total program were directed to the fabrication, modification, procurement, assembly, and checkout of test equipment. A detailed operation test plan (Appendix A) was written and followed explicitly in the conduct of the diffusion test program. Equipment used in the tests is listed in Appendix B. Experimentation was performed involving aerosol generation and downwind sampling of the atomized solution of uranine dye (Appendix C). These tests were performed for the purpose of determining particle sizes of the effluent and ascertaining the best operating conditions for aerosol generation. Photomicrography of the samples studied revealed particle sizes predominantly in the 2- to 10-micron range.

Items on which work was performed included:

. Test trailer	Equipped for test staging and sample handling.
. Stanchions	Fabrication of 138 (5-ft) sampler mounts.
. Electrical network	Design and fabrication of four sets of cables (6500-ft) to furnish power to four sampling arcs on 60° spread at 88, 176, 352, and 704 m from release point.

. Sampler	Modification of 132 Gelman pumps with new electric cord. Preparation of 244 Gelman 2-in. open-face filter holders.
. Particle impactor	Twelve each of Casella and Andersen samplers repaired and checked out.
. Aerosol generator	Two spray gun atomizers mounted on adjustable tripod and tested for aerosol dispensing characteristics.
. Assay instrumentation	Fluorometer repaired and calibrated.
. Meteorological facility	Assembly and checkout of meteorological tower instrumentation. Acquisition of data started 18 December 1963.

The original readiness date planned for 2 December 1963 was changed to early January as a result of the following:

- Delay resulting from higher priorities accorded other Air Force contracts at GD/FW.
- Delay in implementation of the Atmospheric Physics Tower Instrumentation (NARF-64 Statement of Work, Item 33).

The operational phase of the tests was started in the second quarter of the NARF year. Four releases were made on the dates shown in Table 2. A general layout of the sampling network is given in Figure 11. Aerial photographs of the diffusion test area and NARF are shown in Figures 12 through 14. The aerosol dispenser and a typical sampler station are shown in Figures 15 and 16. The fluorometer used for assay of the uranine samples is shown in Figure 17.

Table 2

SUMMARY OF RELEASES AND METEOROLOGICAL CONDITIONS

Release[a]			Source (Uranine)			Meteorological Conditions				Net Radiation (mv)[d]
						Wind		Temperature	Lapse Rate	
No.	Date	Type	Weight (gm)	On (hr)	Off (hr)	Dir. (deg)	Vel. (m/sec)	(°F)	(°F/31 m)	
1	27 Jan	Mild Lapse	40	1543	1556	360 ±10	7.4 ±1.0	58.3[b] 59.5[c]	-1.2	+2.1
2	27 Jan	Weak Inversion	40	1738	1755	008 ±02	4.7 ±1.2	56.5 55.4	+1.1	-0.9
3	21 Feb	Mild Lapse	200	0930	0946	022 ±10	6.4 ±0.8	30.5 32.7	-2.2	+3.1
4	11 Mar	Lapse	200	1516	1528	330 ±15	4.6 ±0.9	60.1 62.9	-2.8	+5.1

[a] Uranine released from a height 6 m above the ground. Sampling heads were 1.5 m above ground.

[b] Mean temperature at 32 m.

[c] Mean temperature at 1 m.

[d] 1 mv = 1/8.67 langley or 1 gm-cal/cm^2-min.

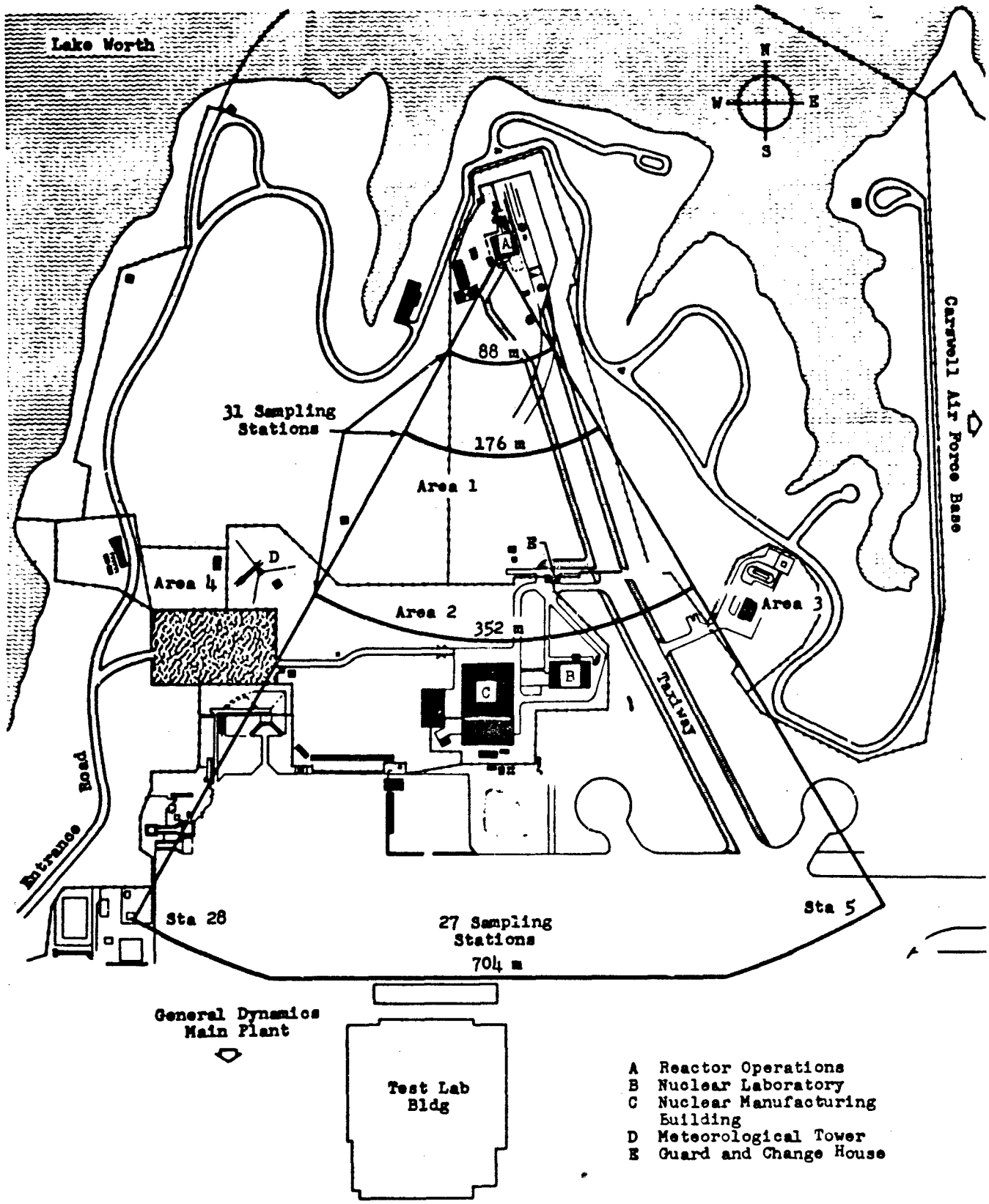

Figure 11 General Layout of the Sampling Network in the NARF and Adjacent Areas

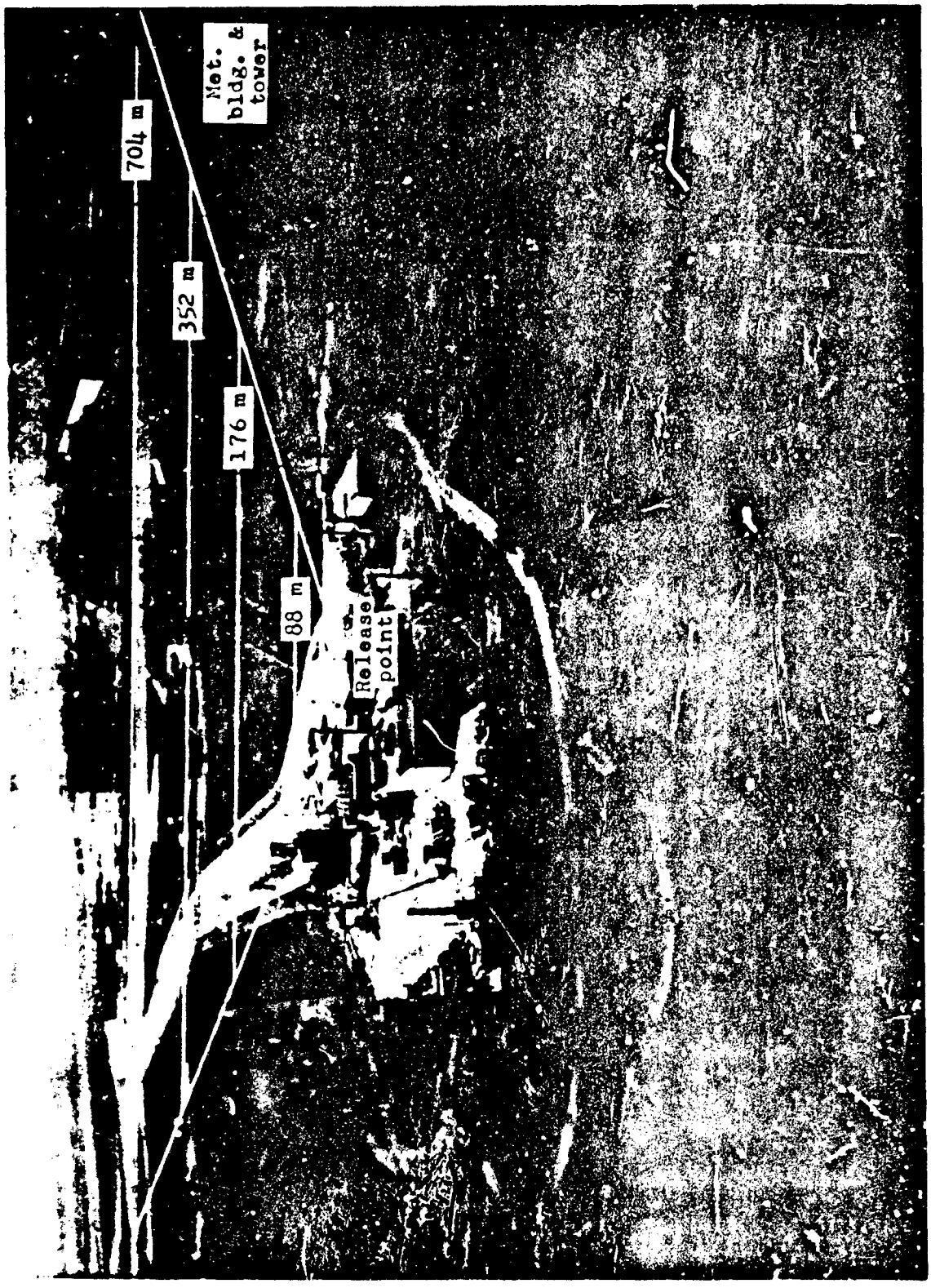

Figure 12. NARF and GD/FW Plant Site Showing the Reactor Operations Area, the Sampling Arcs, the Meteorological Building and Tower, and the Release Point

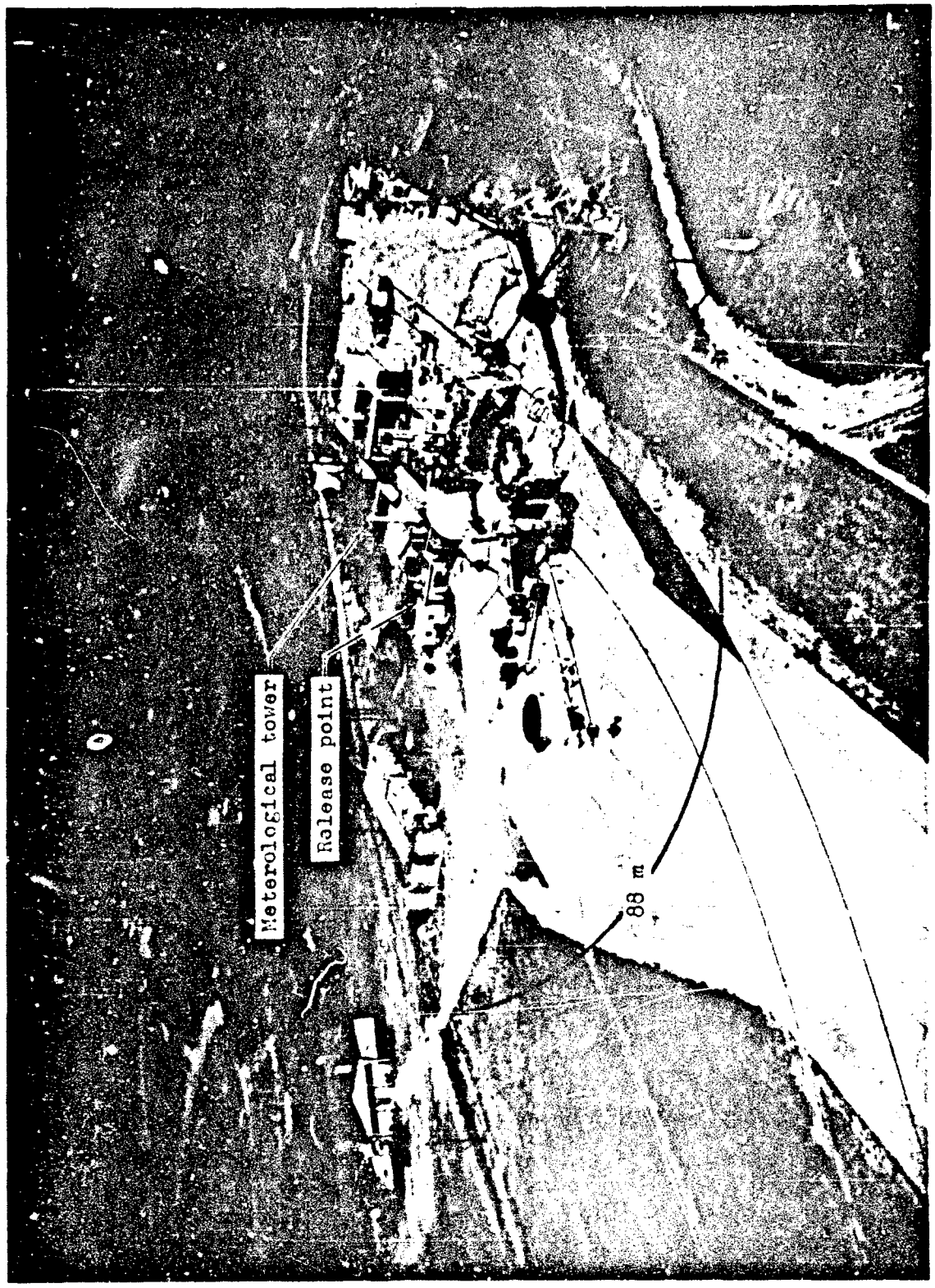

Figure 13. Reactor Operations Area Showing the 88-m Arc, the Release Point, and the 15-m Wind and Temperature Tower

Figure 14. Reactor Operations Area Showing Expanse of Adjoining Lake Worth as an Atmospheric Diffusion Factor

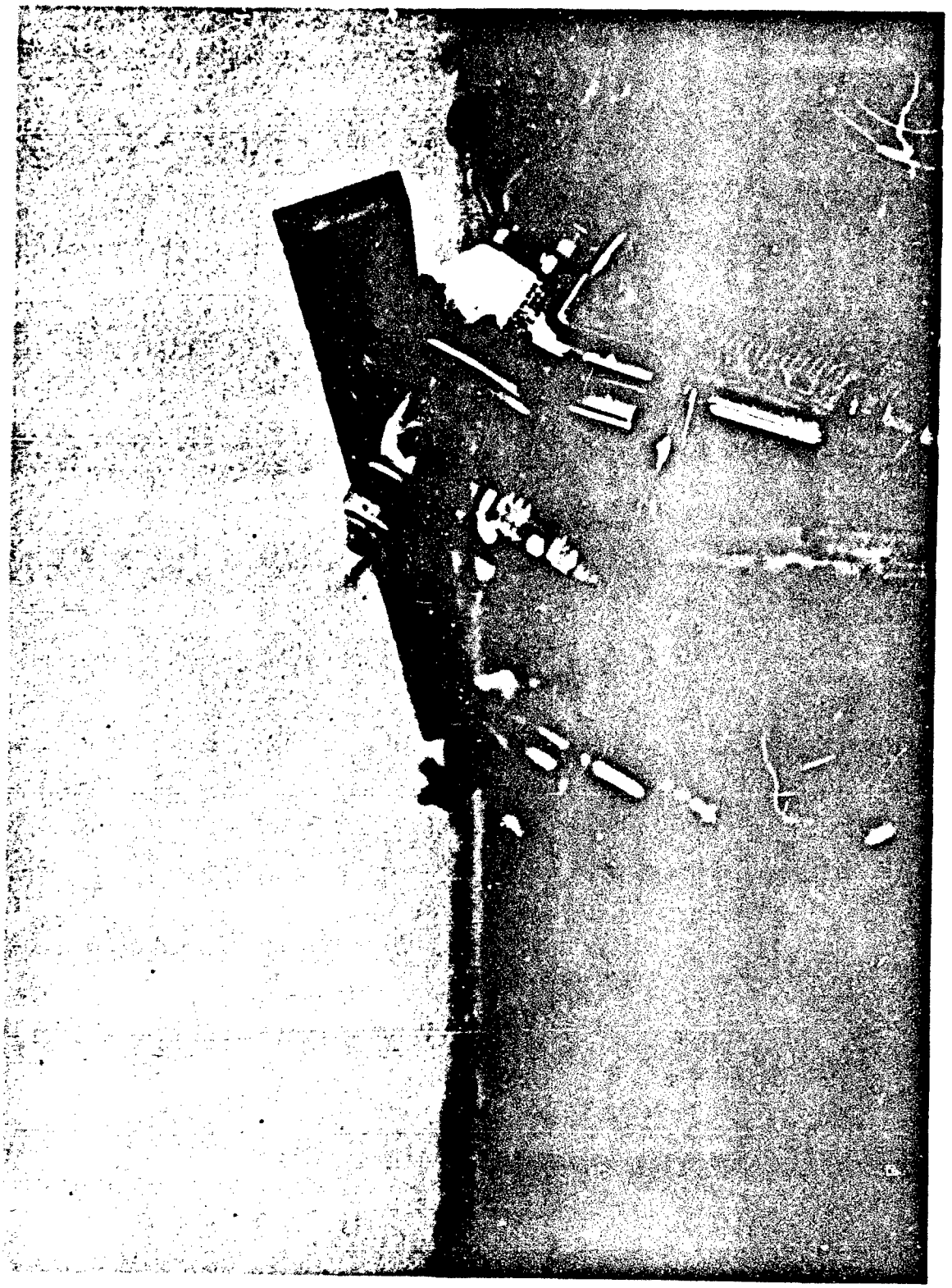

Figure 15. Aerosol Dispenser with Pressure and Spray Adjustments

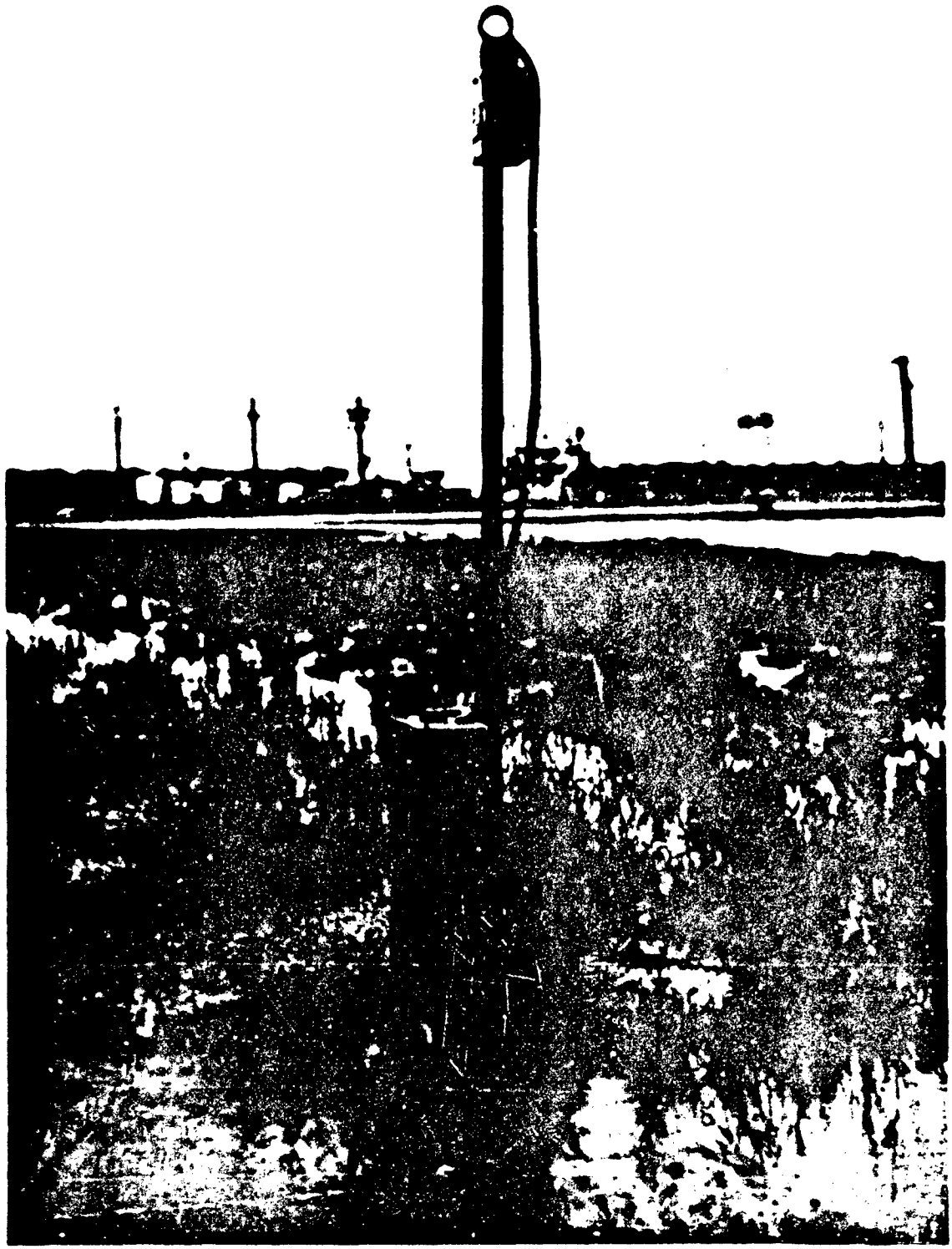

Figure 16. Aerosol Sampling Station Showing the Bantam Pump on Portable 5-ft Stanchion, the 2-in. Filter Assembly, and the Warning Light

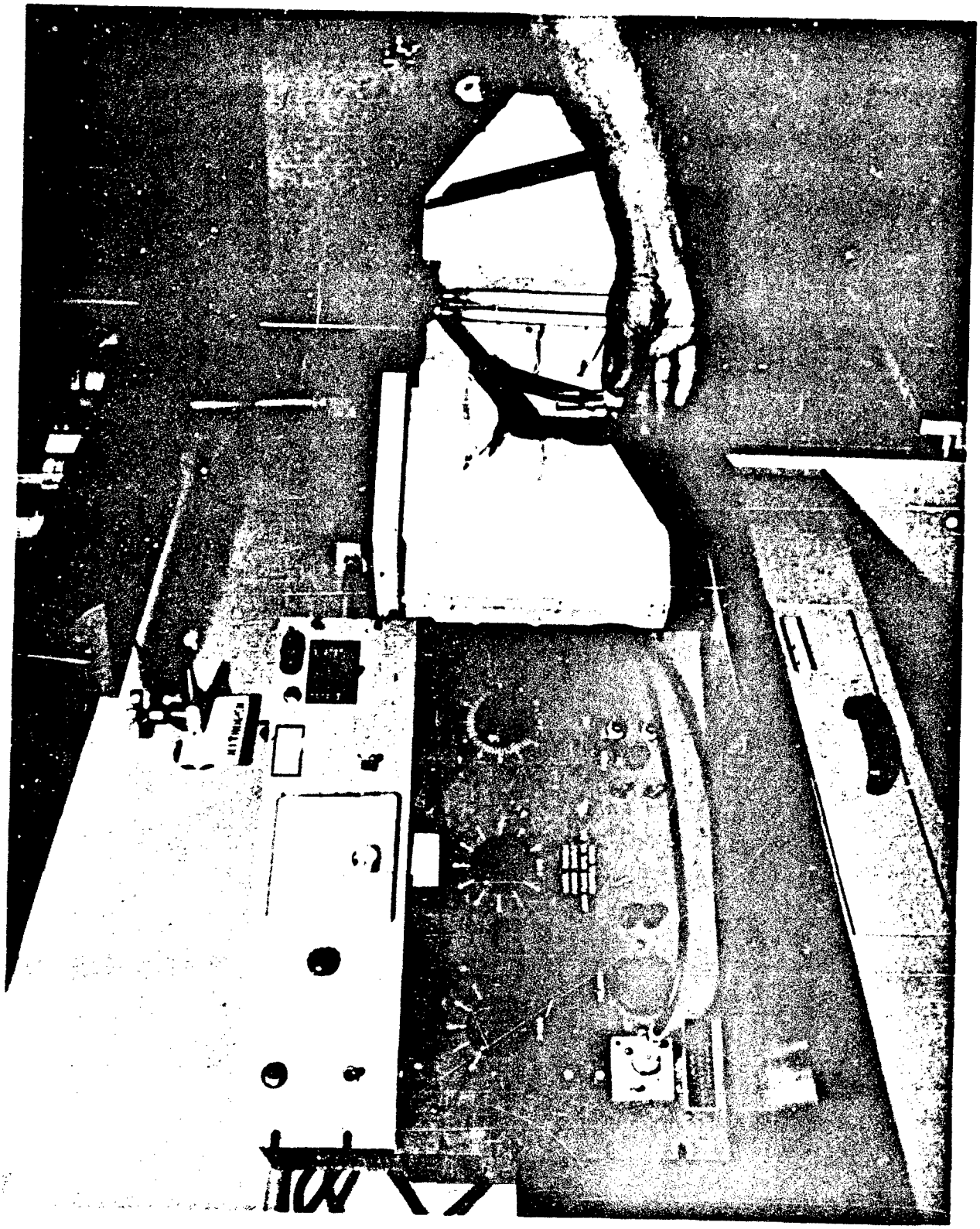

Figure 17. Microvoltammeter and Fluorometer Used for Assay of Uranine Samples

The network equipment, the assay instrumentation, and the meteorological instrumentation utilized during the tests functioned satisfactorily. Regarding the scheduling of the remaining five tests, however, two problems arose during the test period. One was that of getting favorable meteorological conditions over the network, i.e., a northerly wind with an inversion. The other was the fallout of uranine droplets (aqueous) after the spray had been released to the atmosphere by the dispenser. The source term Q for the diffusion equation cannot be accurately evaluated when the amount of fallout is not known. The matter was investigated in a series of experiments to see whether the fallout could be essentially eliminated under warmer and drier atmospheric conditions.

The extent of fallout of aqueous aerosol varies inversely with the rate of evaporation of water from the uranine nuclei. The rate of evaporation varies inversely with the relative humidity of the atmosphere and the dygroscopicity of the solute, and it varies directly with air temperature, vapor pressure of the solvent, wind speed, and pressure of the air passing through the aspirator (see Appendix C). Preliminary tests revealed the following observations relative to fallout (uranine solution droplet) formation. The fallout, resulting from a slow rate of evaporation occurred when:

relative humidity $> 50\%$ and air temperature $< 35^{\circ}F$
$> 60\%$ $< 40^{\circ}F$
$> 80\%$ $< 50^{\circ}F$
$> 90\%$ $< 85^{\circ}F$

An experiment was performed during Test 3 in which fallout plates were placed on the ground in a configuration of a double cross along the grid centerline and at the intersection with Arc "A." The plates were 3-in. glass discs coated with glycerin-gel. One plate was placed at the base of each of three stations (10, 16, and 22). Five were placed on the centerline and two were placed on a line which crossed the centerline at a point about 150 ft from the aerosol generator. The quantities of uranine collected on the plates were compared with the quantities collected by the sampler filters mounted 5 ft above the plates. To obtain more representative concentrations of the cloud an average was taken of the three filters: one directly above, one to the right, and one to the left. As the samplers were not operating at isokinetic flow rates, a correction factor of 9.1 was applied to the quantities of uranine measured on the filters in order to relate these values to the amounts of uranine deposited on the fallout plates and to the wind speed. The results of this test are shown below:

Station	Uranine Fallout (10^{-8}gm/cm^2)	Collected Filter (10^{-8}gm/cm^2)		Ratio of Fallout to Filter (%)	
10	0.97	2.3[a]	20.8[b]	43[a]	4.7[b]
16	6.2	42.2	382	15	1.6
22	6.9	38.2	349	18	2.0
			Avg	25.3	2.7

[a]Actual concentrations

[b]Isokinetic factor applied to actual concentrations

The quantities of uranine collected by each of the ten fallout plates on the array are given below:

Position Distance Downwind on Centerline (ft)	Concentration on Double Cross (10^{-8}gm/cm^2)		
150	0.5	0.5	6.0
200		6.0	
250		2.4	
300 (A Arc)	0.97	6.2	6.9
350		2.0	
400		1.0	

Another test was performed under similar atmospheric conditions where 25 gm of uranine dissolved in 500 ml of water was sprayed directly over 120 ft^2 of mylar sheet which extended 28 ft downwind. The amount of uranine deposited on the plastic as aqueous fallout was assayed to be 1.65×10^{-2} gm. Using this quantity, the fallout concentration was computed to

be 15 x 10^{-8} gm/cm^2 on an area between 10 and 28 ft downwind. Using the data for fallout at Arc A (above) and the close-in concentration measured on the mylar, it was calculated that 4.2 gm of the 25 gm of uranine (source) was deposited as fallout.

Meteorological and operations test data generated during the four tests are given in Tables 3 through 6. Detailed sampling data are given in Appendix D. In general, the four diffusion tests were conducted in close accordance with the Operations Plan.

4.2 Test Results

In order to compare the depletion factors obtained from the various releases, the network arc-sample profiles (Figs. 18 through 21) were divided by the source strengths and the isopleths plotted from the resulting network depletion factors. These isopleths, shown in Figures 22 through 25, indicate that, in general, releases made during an inversion or neutral condition produce larger and narrower clouds than those made during a lapse. It should be pointed out here that the cloud widths as well as the arc integral values are dependent upon wind direction variation. In addition, release height and fallout of source near the release point are significant factors affecting cloud depletion. The diffusion equation accounts for height of release, but it does not account for the effect of fallout observed (visually) during the releases. The results

Table 3

METEOROLOGICAL AND OPERATIONS TEST DATA

Test 1

27 January 1964

Source: Uranine

Source Quantity: 40 grams in 4 liters of water

Release Conditions

Mean lapse rate: $\Delta T/(32 - 1\ m) = -1.2^{o}F/31\ m$
Lapse release

Release height: 6 m
Generator on top of Nuclear Operations Building

Sampling Times

System	Time of Day On	Time of Day Off
Aerosol	1543	1556
Arc A	1543	1600
Arc B	1543	1602
Arc C	1543	1604
Arc D	1543	1608

Meteorological Conditions

Element	Time of Measurement t_o - 10 min	t_o	t_o + 5 min	t_o + 10 min	t_o + 20 min
Wind					
Direction (deg)	360	010	360	009	032
Speed (m/sec)					
32 m	6.8	7.6	8.4	7.7	7.1
4 m	5.2	5.2	6.4	5.8	5.0
Temperature (^{o}F)					
32 m	58.2	58.7	58.2	58.1	58.3
1 m	59.7	59.7	59.8	59.2	59.2
Net radiation (mv) 6 m	+2.6	+2.3	+2.2	+2.0	+1.7

Relative humidity: 48%; sky: overcast; barometric pressure: 29.40 in.

Table 4

METEOROLOGICAL AND OPERATIONS TEST DATA

Test 2

27 January 1964

Source: Uranine

Source Quantity: 40 grams in 4 liters of water

Release Conditions

Mean lapse rate: $\Delta T/(32 - 1\ m) = +1.1^{\circ}F/31\ m$
Inversion release

Release height: 6 m
Generator on top of Nuclear Operations Building

Sampling Times

System	Time of Day On	Off
Aerosol	1738	1755
Arc A	1738	1800
Arc B	1738	1800
Arc C	1738	1805
Arc D	1738	1805

Meteorological Conditions

Element	Time of Measurement t_o - 10 min	t_o	t_o + 5 min	t_o + 10 min	t_o + 20 min
Wind					
Direction (deg)	005	009	007	008	004
Speed (m/sec)					
32 m	8.2	5.2	6.6	5.6	6.0
4 m	3.8	4.0	3.8	3.9	4.7
Temperature ($^{\circ}F$)					
32 m	57.5	57.0	56.6	56.5	56.2
1 m	56.6	56.3	55.7	55.2	54.8
Net radiation (mv)					
6 m	-0.8	-0.9	-0.9	-0.9	-1.0

Relative humidity: 48%; sky: overcast; barometric pressure: 29.40 in.

Table 5

METEOROLOGICAL AND OPERATIONS TEST DATA

Test 3 — 21 February 1964

Source: Uranine — Source Quantity: 200 grams in 4 liters of water

Release Conditions

Mean lapse rate: $\Delta T/(32 - 1\ m) = -2.2^{o}F/31\ m$
Lapse release

Release height: 6 m
Generator on top of Nuclear Operations Building

Sampling Times

System	Time of Day On	Off
Aerosol	0930	0946
Arc A	0930	0952
Arc B	0930	0955
Arc C	0930	1000
Arc D	0930	1010

Meteorological Conditions

Element	Time of Measurement t_o - 10 min	t_o	t_o + 5 min	t_o + 10 min	t_o + 20 min
Wind					
Direction (deg)	015	021	022	022	360
Speed (m/sec)					
32 m	7.5	6.6	6.6	4.7	5.5
4 m	6.0	5.0	4.8	3.8	4.0
Temperature (^{o}F)					
32 m	30.0	30.3	30.5	30.7	31.6
1 m	31.6	31.8	32.9	32.8	34.5
Net radiation (mv) 6 m	+2.5	+2.9	+3.1	+3.4	+3.9

Relative humidity: 57%; sky: clear; barometric pressure: 29.64 in.

Table 6

METEOROLOGICAL AND OPERATIONS TEST DATA

Test 4

11 March 1964

Source: Uranine

Source Quantity: 200 grams in 4 liters of water

Release Conditions

Mean lapse rate: $\Delta T/(32 - 1\ m) = -2.8^{o}F/31\ m$
Lapse release

Release height: 6 m
Generator on top of Nuclear Operations Building

Sampling Times

System	Time of Day On	Off
Aerosol	1516	1528
Arc A	1516	1535
Arc B	1516	1540
Arc C	1516	1545
Arc D	1516	1550

Meteorological Conditions

Element	Time of Measurement t_o - 10 min	t_o	t_o + 5 min	t_o + 10 min	t_o + 20 min
Wind					
Direction (deg)	339	347	318	324	345
Speed (m/sec)					
32 m	5.6	4.4	5.0	6.2	5.6
4 m	3.8	4.0	4.0	3.8	3.6
Temperature (^{o}F)					
32 m	59.2	59.9	60.0	60.7	60.2
1 m	61.4	63.9	62.6	63.0	62.7
Net radiation (mv)					
6 m	+5.7	+5.4	+4.9	+4.9	+4.8

Relative humidity: 49%; sky: overcast; barometric pressure: 29.41 in.

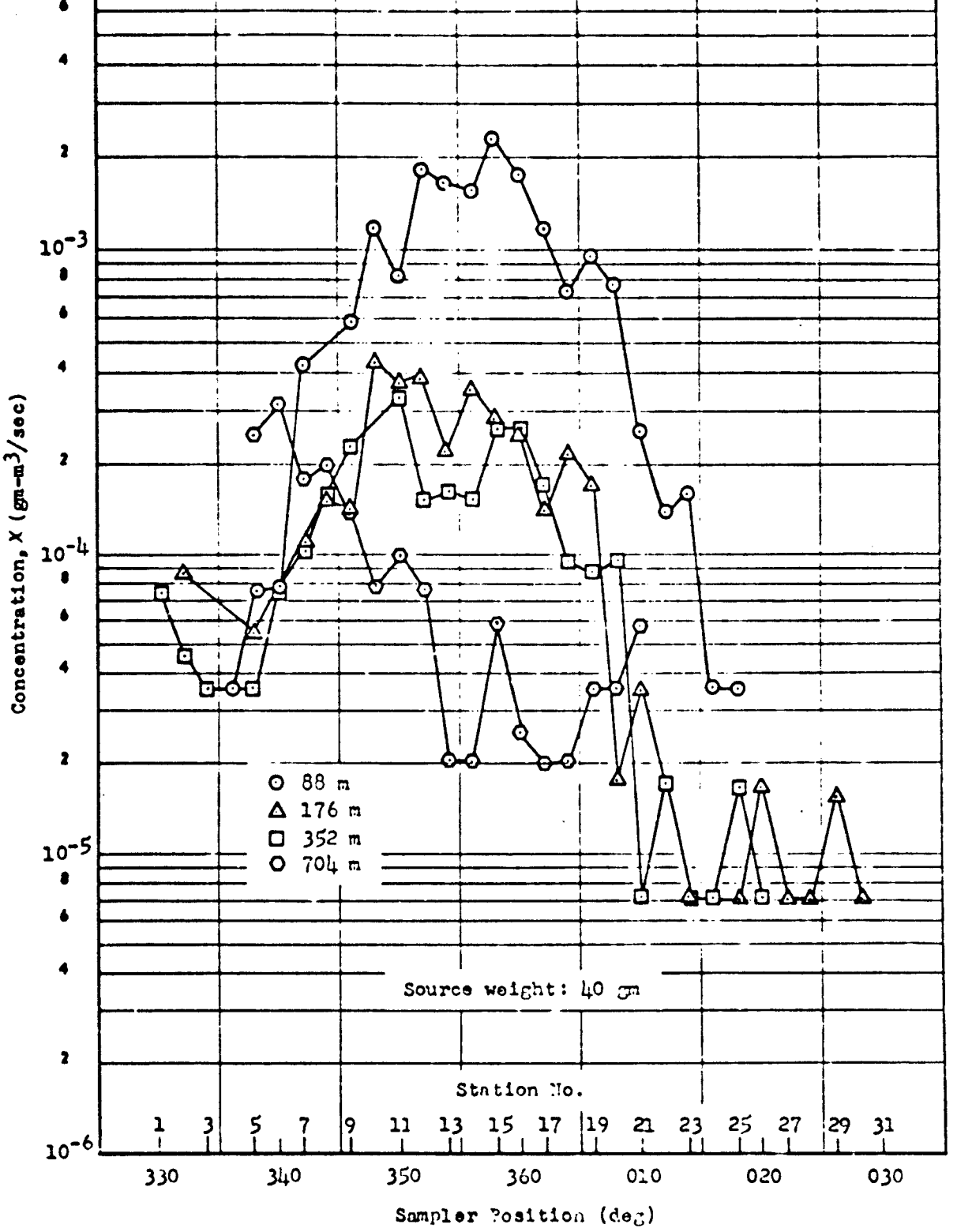

Figure 18 Arc Profiles of Uranine Samples Collected under Mild Lapse for Test 1

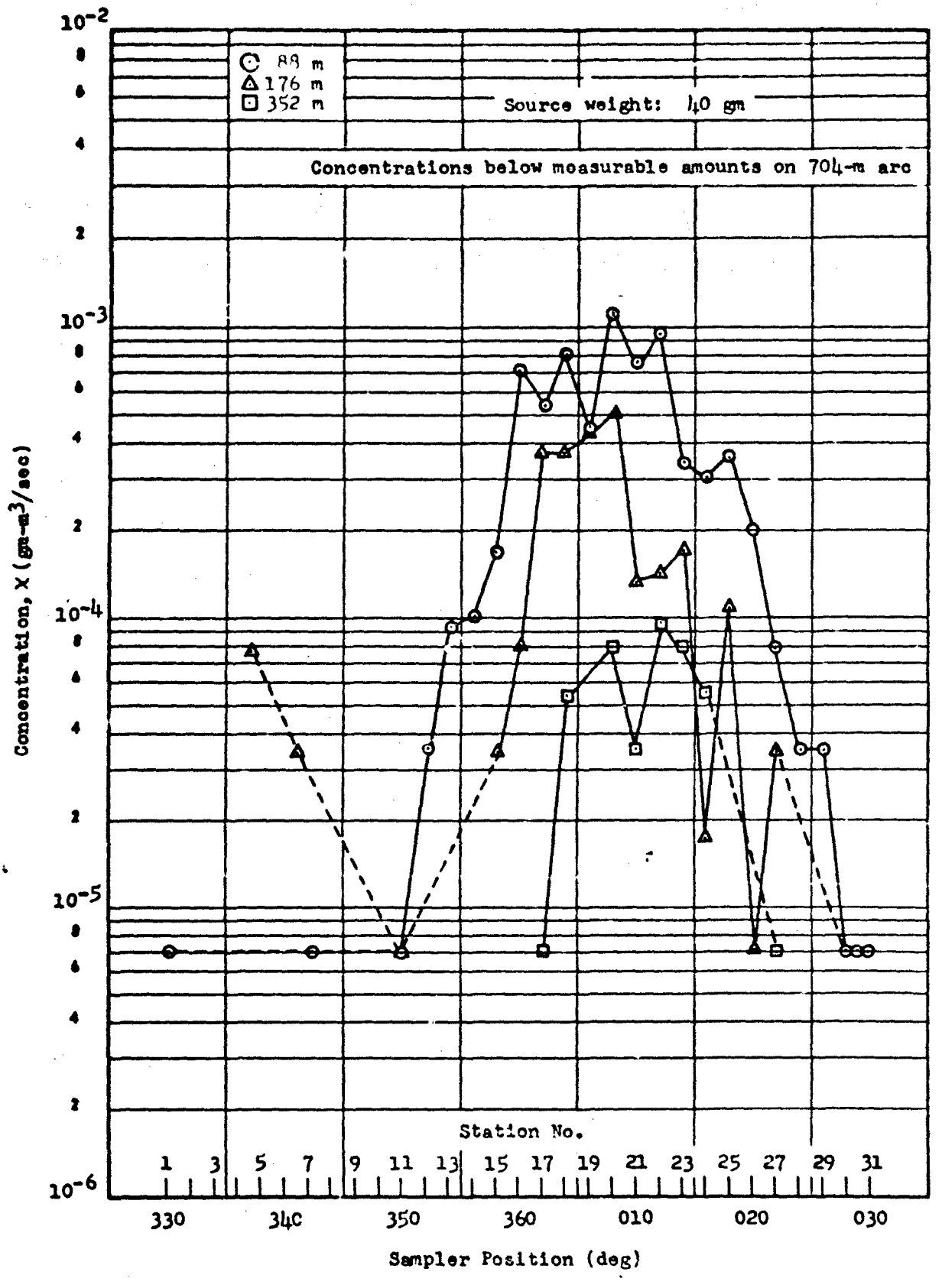

Figure 19 Arc Profiles of Uranine Samples Collected under Weak Inversion for Test 2

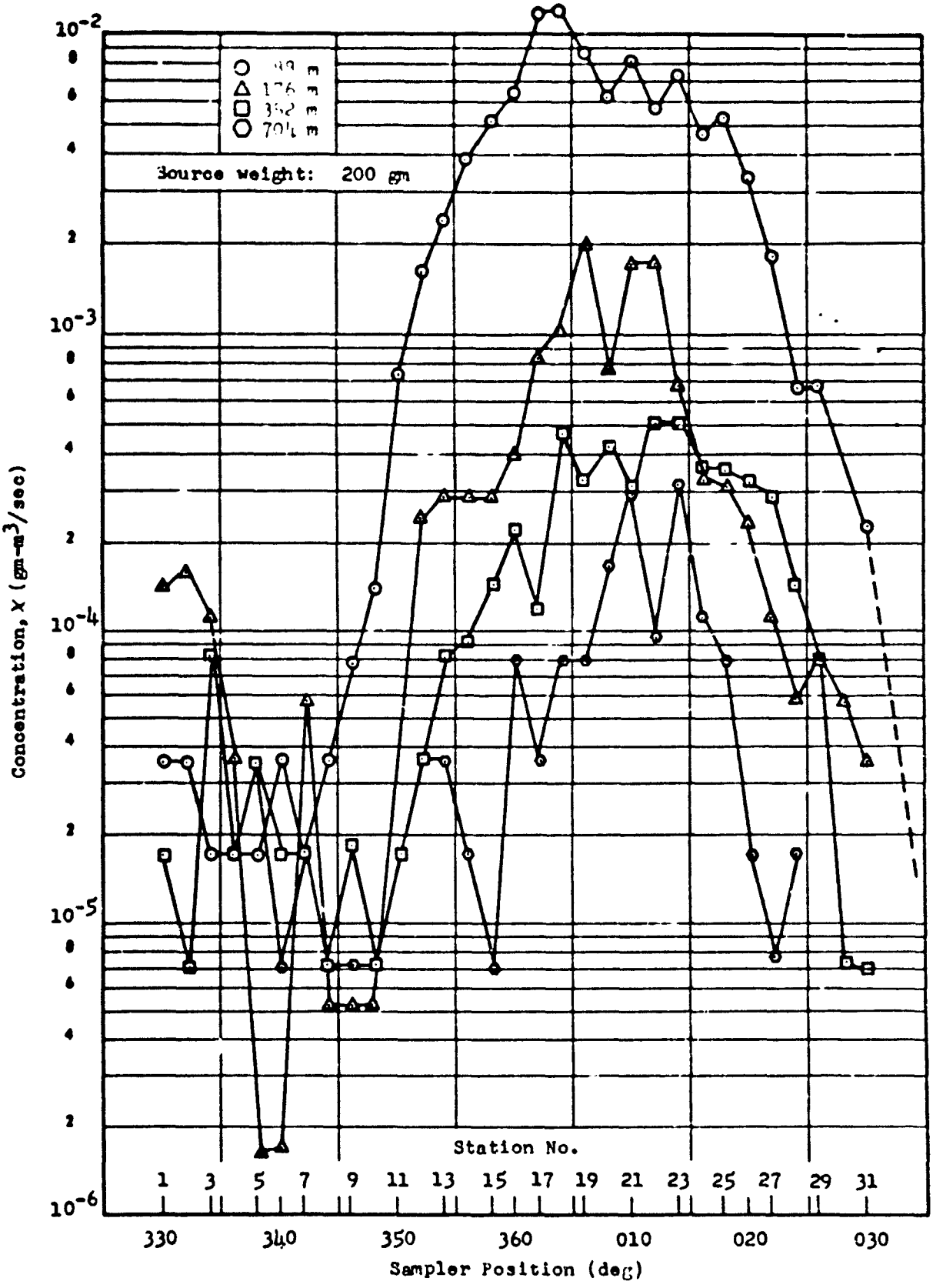

Figure 20 Arc Profiles of Uranine Samples Collected under Mild Lapse for Test 3

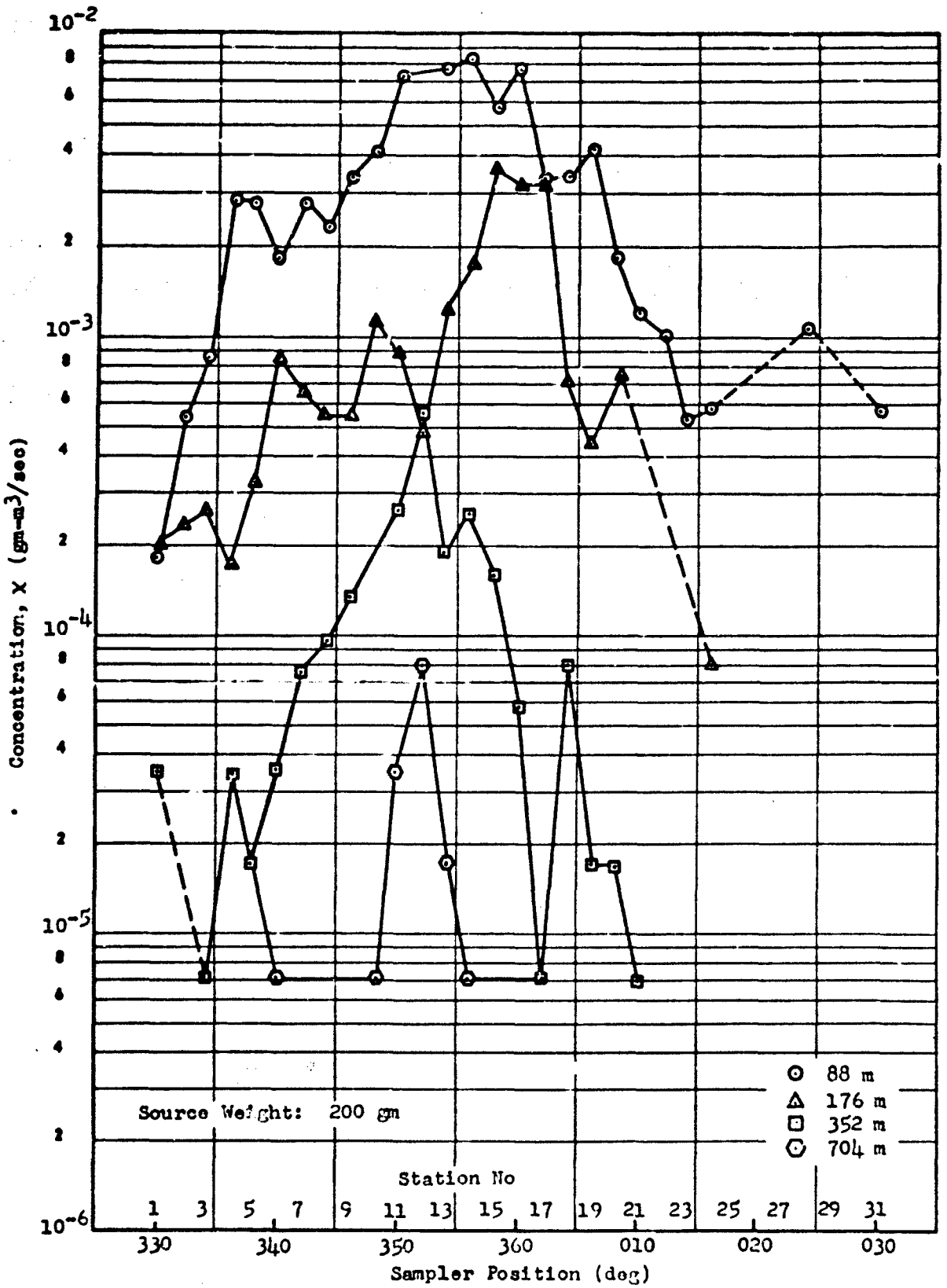

Figure 21 Arc Profiles of Uranine Samples Collected under Normal Lapse for Test 4

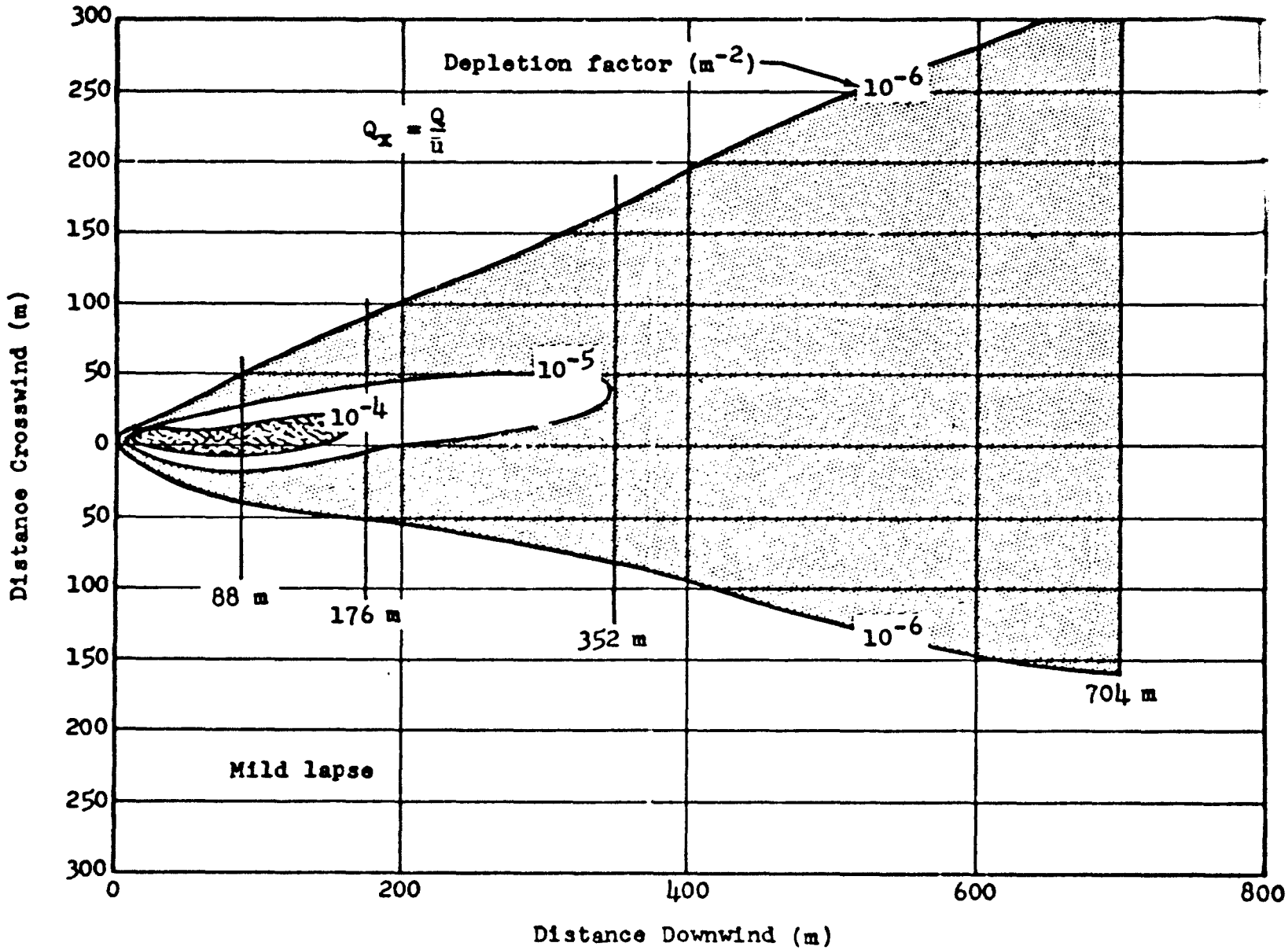

Figure 22 Depletion Isopleths (Q/u Values) for Test 1

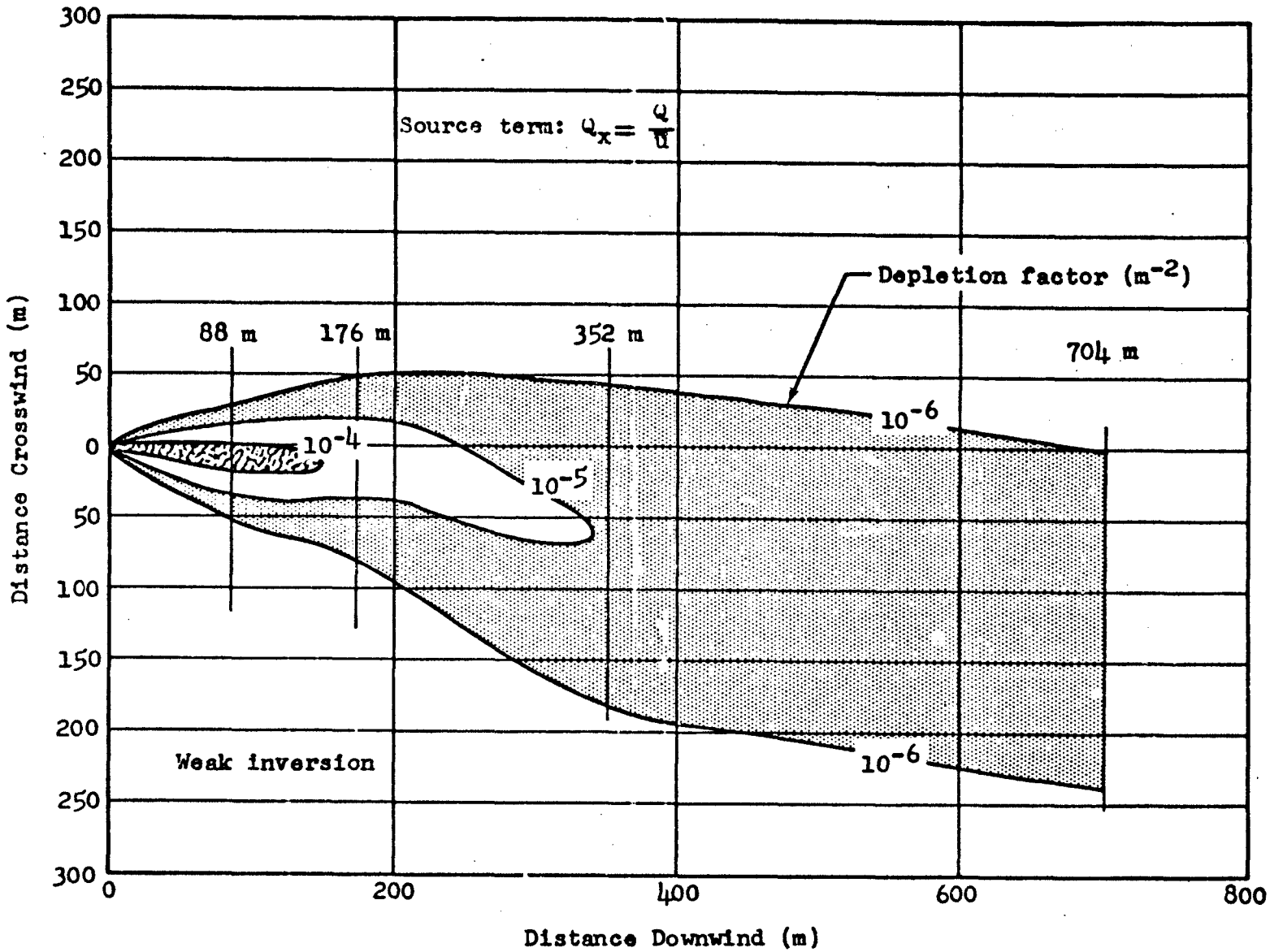

Figure 23 Depletion Isopleths (X/Q_x Values) for Test 2

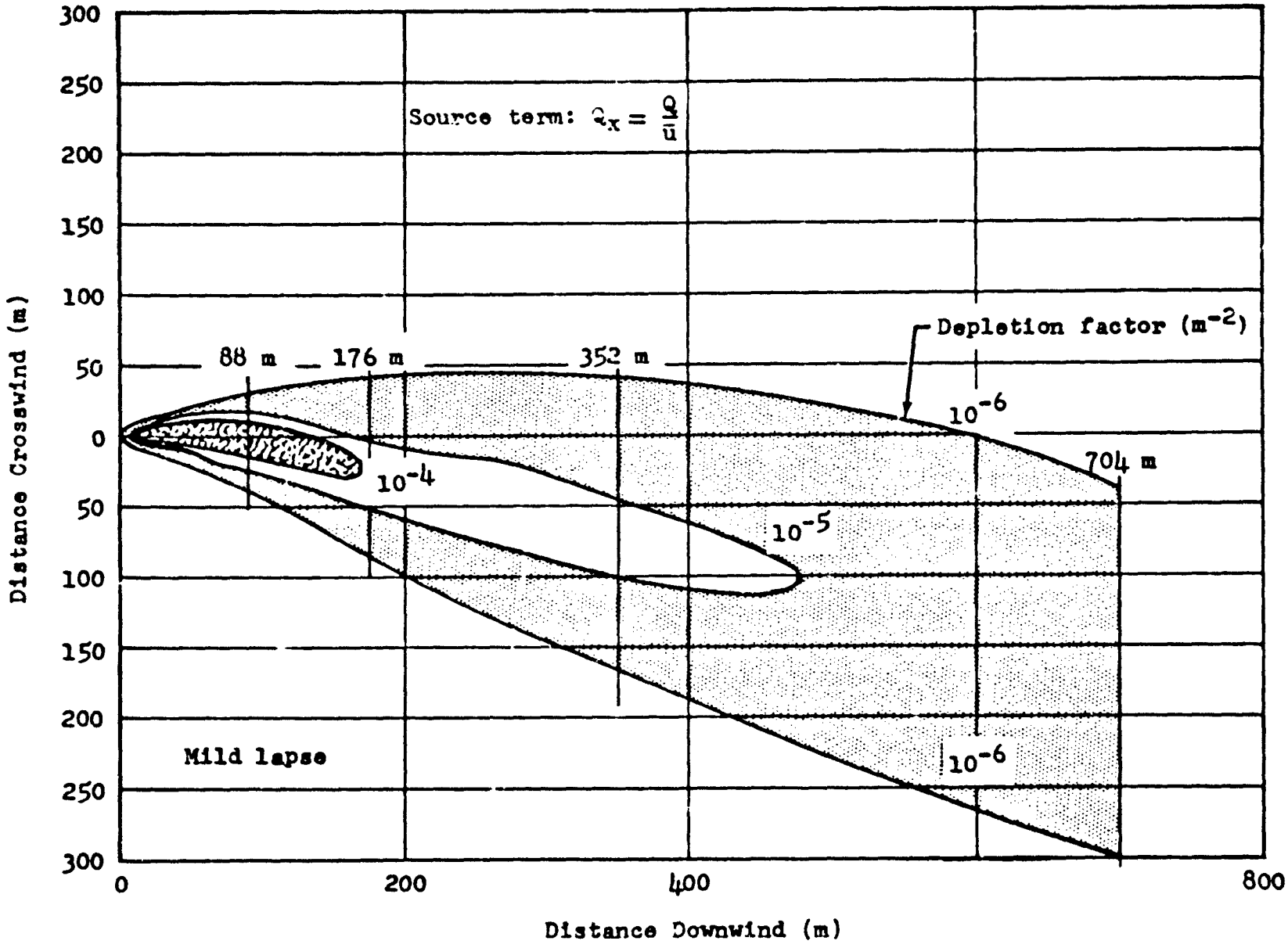

Figure 24 Depletion Isopleths (X/Q_x Values) for Test 3

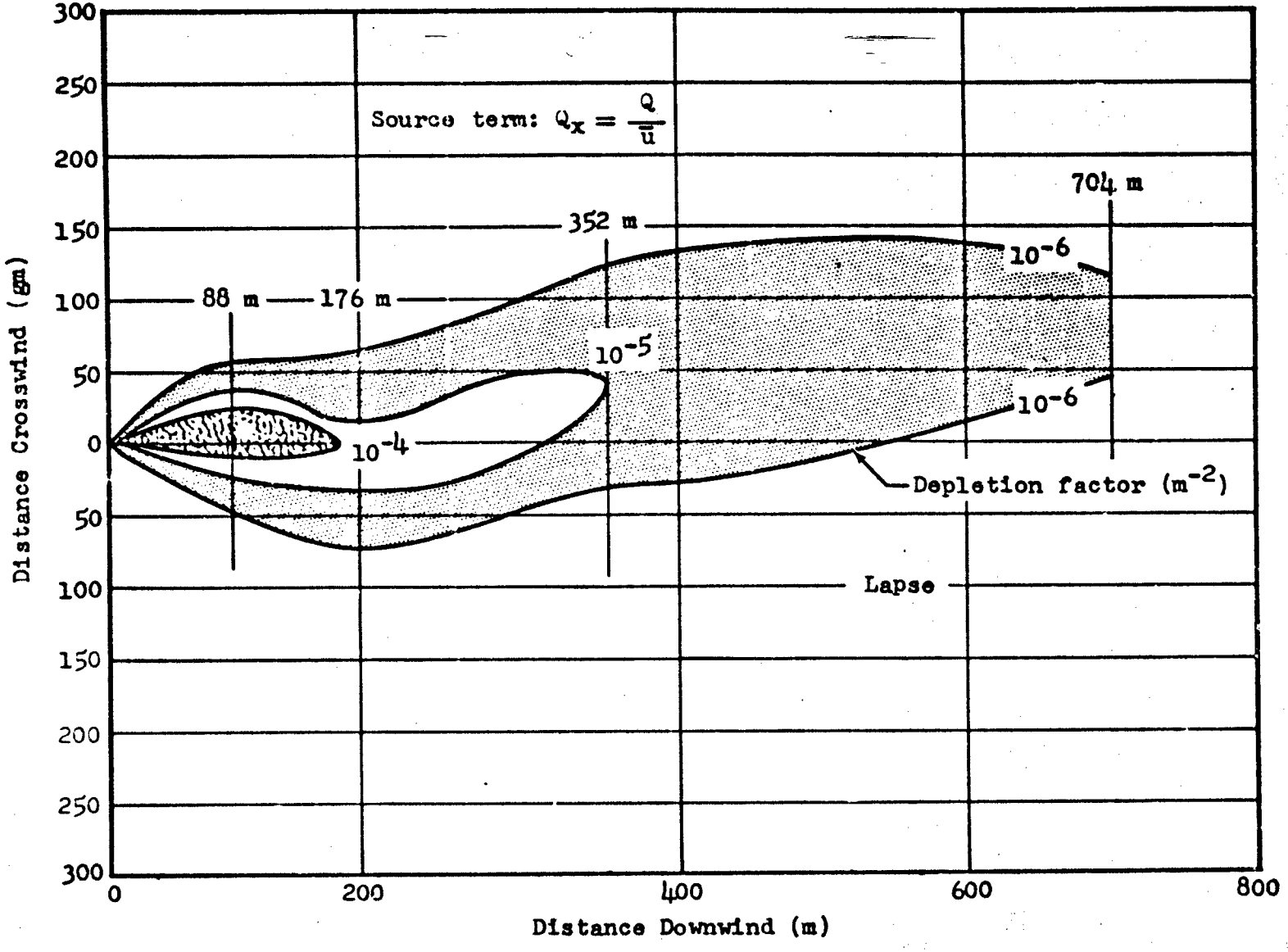

Figure 25 Depletion Isopleths (χ/Q_x Values) for Test 4

of the fallout investigations show that under the atmospheric conditions accompanying Test 3, the aerosol cloud is depleted by fallout of aqueous droplets of uranine within the range of from 3% to 25%, depending upon the distance downwind from the source and the horizontal spread of the cloud. Starting at 10 ft from the source and extending downwind to the limits of fallout detection, it appears that an overall average of 15% may be applied in correcting the source term Q and the depletion factors. As a consequence for Tests 1 through 4, Q should be reduced by 15% and the values for the depletion factors (Table 7) should be multiplied by 1.15. The diffusion-parameter constants (Table 8) are exponentials and would not be significantly affected by this modification of input data.

Figure 26 shows depletion isopleths (X/Q values) based on the average Stanford and Prairie Grass parameters. In the absence of buildings and concrete paved surface, these parameters were measured for flat terrain and were expected to overestimate centerline maximum concentrations and underestimate the cloud widths over the NARF area. A comparison of predicted (Refs. 3 and 8) with measured centerline maximum concentrations and cloud widths substantiates these expectations. Maximum concentrations and cloud widths obtained from NARF diffusion-test data are shown in Figures 27 and 28, respectively; for comparison, predicted values are also shown. A comparison of isopleth areas with respect to values predicted

Table 7

EFFLUENT DEPLETION FACTORS MEASURED FOR THE NARF AREA

Test	88-m Arc	176-m Arc	352-m Arc	704-m Arc
1	3.6×10^{-4}	7.0×10^{-5}	4.2×10^{-5}	4.2×10^{-6}
2	1.1×10^{-4}	5.2×10^{-5}	0.9×10^{-5}	1.0×10^{-6}
3	2.8×10^{-4}	5.6×10^{-5}	1.2×10^{-5}	7.5×10^{-6}
4	1.7×10^{-4}	6.6×10^{-5}	1.0×10^{-5}	1.6×10^{-6}
Avg	2.3×10^{-4}	6.1×10^{-5}	1.8×10^{-5}	3.6×10^{-6}

Table 8

DIFFUSION-PARAMETER CONSTANTS EVALUATED FOR THE NARF AREA

Test	Parameters			
	Cy	m_y	C_z	m_z
1	0.39	1.09	0.06	0.54
2	0.29	1.20	0.16	0.75
3	1.01	0.92	0.07	1.06
4	1.48	0.94	0.07	0.91

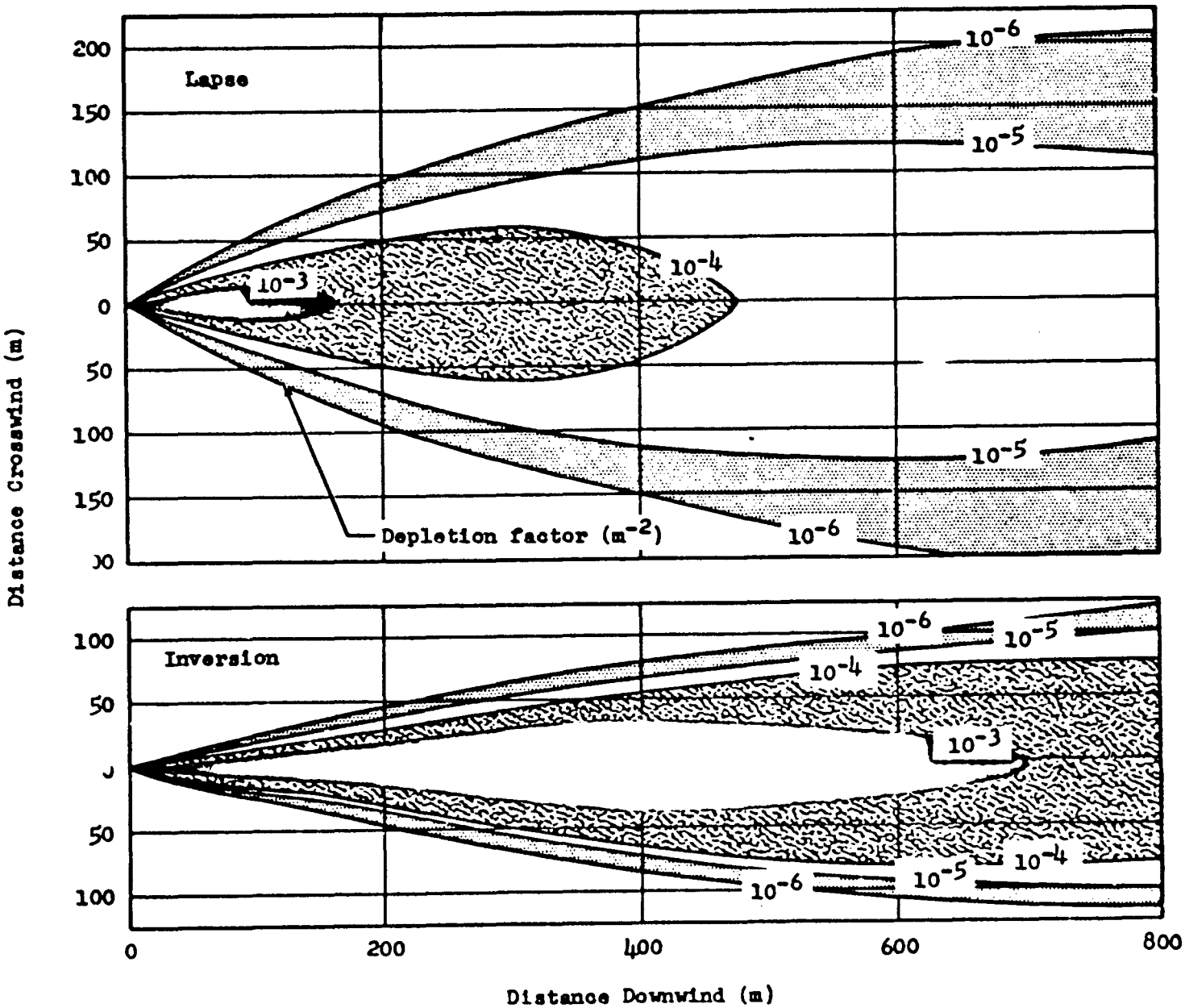

Figure 26 Predicted Isopleths: Parameter Values Based on Stanford and Prairie Grass Results

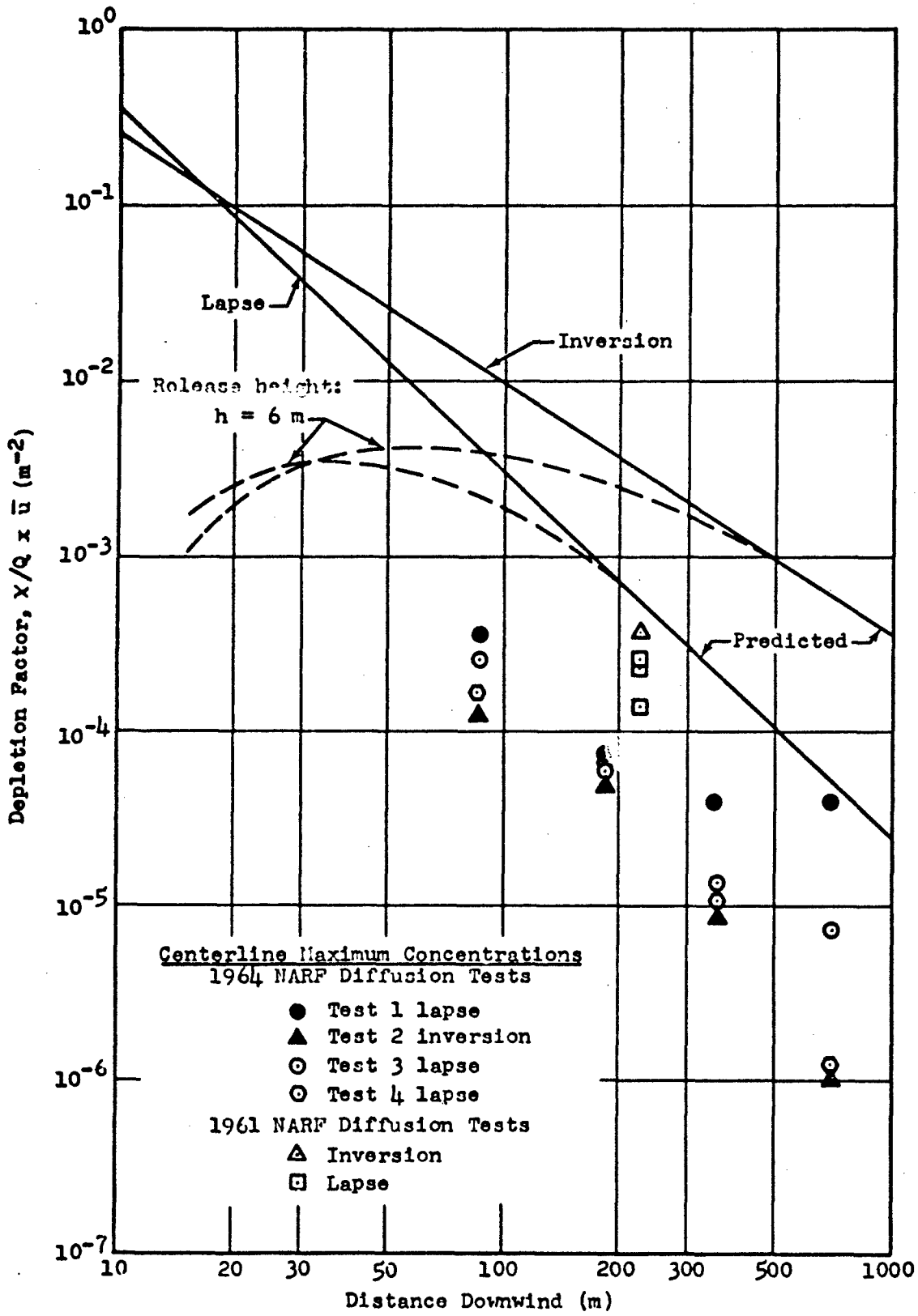

Figure 27 Comparison of Predicted Depletion with Experimental Results

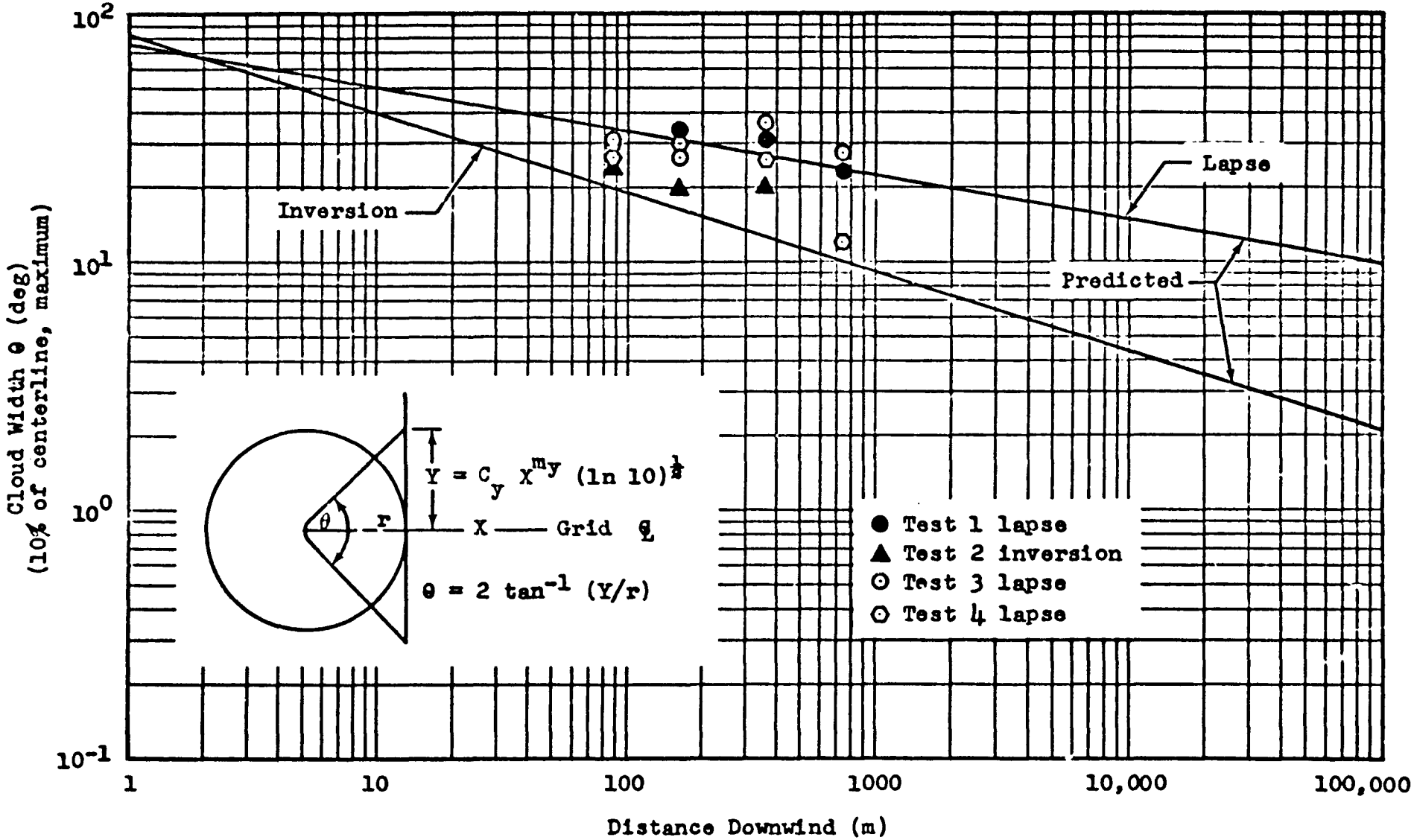

Figure 28 Comparison of Predicted Cloud Widths with Test Results

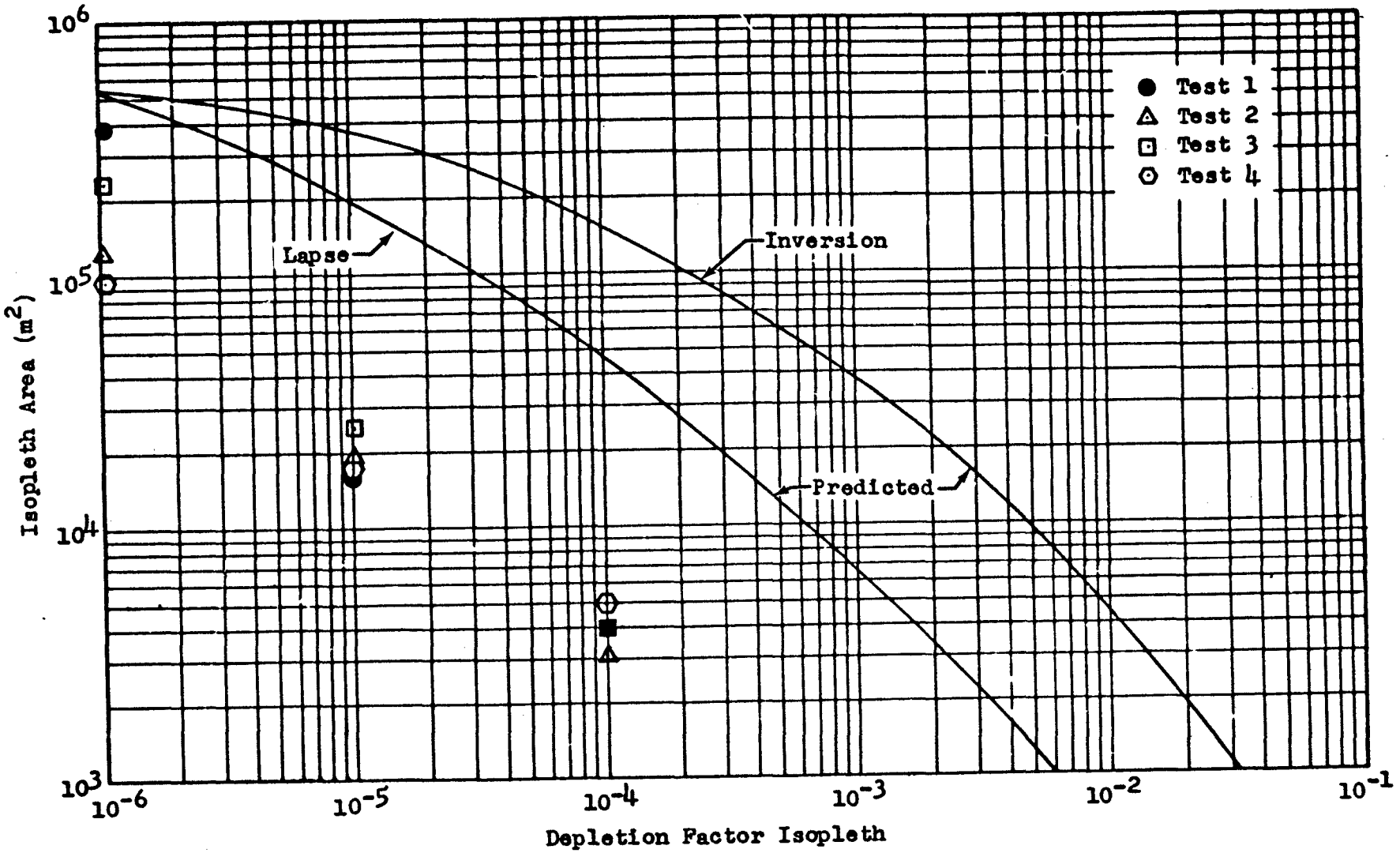

Figure 29 Comparison of Isopleth Areas with Those for Stanford and Prairie Grass Tests

downwind is shown in Figure 29. Reasonable agreement, in some categories, is observed between the NARF and other diffusion test results. However, to account for the deviations, the effects of release height, wind variability, surface, and structure interference must be considered in the test evaluation. These factors are sufficient to cause significant variance with respect to atmospheric diffusion in the NARF area as compared to the phenomenon observed in other environments.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results of the uranine releases show that aerosol-type effluents released from a point near the GTR are diffused within a half-mile range to a depletion significantly less than that predicted by the theoretical diffusion model. The values of the depletion factors are considerably lower than those actually used to maintain the nuclear safety margin in the environs of NARF operations.

It should be pointed out, however, that the four tests are not sufficient in number and in type to provide substantial statistical data for diffusion parameter evaluations for this particular area. The tests did not include a wide range of lapse rates, i.e., rates from highly unstable lapse to strong inversions. Furthermore, the effects of release height and fallout were not comprehensively investigated. Under a strong inversion, a ground release of radioactive effluent, without excessive fallout, would probably yield arc concentrations with factors of from 10 to 500 greater than those produced in these tests. Comparisons of the evaluations of parameters m_y, m_z, C_y, and C_z calculated for these releases and for the Stanford, Prairie Grass, Tory II-A, and FRT-I tests are given in Table 9. The variances and apparent anomalie shown by the NARF diffusion tests reflect the need for more

diffusion data to be obtained under many release, sampling, and meteorological conditions. The method of parametric evaluation applied here is the one developed by Couchman (Ref. 3).

Table 9

COMPARISON OF NARF DIFFUSION PARAMETERS WITH THOSE EVALUATED FOR STANFORD AND PRAIRIE GRASS EXPERIMENTS

Atmospheric Condition	Parameters			
	C_y	m_y	C_z	m_z
	NARF Diffusion Tests			
Lapse	1.06±.36(3)	0.98±.06(3)	0.07±.01(3)	0.84±.13(3)
Inversion	0.29 (1)	1.20 (1)	0.16 (1)	0.75 (1)
Average	0.72±.40(4)	1.30±.09(4)	0.09±.03(4)	0.81±.21(4)
	Stanford-Prairie Grass Parameters (Averaged)			
Lapse	0.45±.18(41)	0.83±.09(43)	0.03±.03(43)	0.27±.29(43)
Inversion	0.43±.21(37)	0.69±.10(36)	0.20±.12(36)	0.73±.18(37)
Average	0.44±.20(78)	0.76±.12(80)	0.11±.07(79)	1.02±.24(80)

Numbers in parentheses indicate the number of values averaged.

Because of the orientation of the sampling network and the prevailing southerly winds, it was not feasible to conduct additional tests under strong inversions during the spring and summer months. Furthermore, the probability of moderate-to-strong temperature inversions occurring with

northerly winds in this area during the summer is relatively low. Since meteorological conditions essentially control the test schedule, any attempt to continue testing after March must be considered uneconomical. Northerly wind flow, under an inversion, occurs much more frequently in this area during the fall and winter months.

Additional diffusion operations were curtailed by a local requirement that the sampling network be cleared from the test area during spring and summer.

5.2 Recommendations

In view of insufficient and restrictive data produced by the diffusion tests, comprehensive conclusions cannot be made with respect to NARF diffusion parameter evaluations. To overcome this inconclusiveness, it is recommended that more diffusion tests be conducted in the NARF area. Effluent releases should be made under the widest range of meteorological conditions which normally occur in this area. The most favorable time for the strong inversions to occur in the Fort Worth area is during fall and winter. Other factors to be studied would include the effect of release height, stack exhaust rate, effluent temperature, particle size, agglomeration, and fallout. These investigations would be facilitated by employment of a dual-tracer technique, described in Reference 15.

The many variables which influence atmospheric diffusion

make it necessary that extensive experimentation be conducted in a given locality in order to gain adequate knowledge and evaluation of the hazard associated with the release of radioactivity to the atmosphere.

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APPENDIX A

OPERATIONS PLAN FOR NARF

DIFFUSION STUDIES

(Revised)

GENERAL

Fluorescent dye (uranine-water solution) will be released to the atmosphere from specified heights near the NARF reactors (GTR and ASTR) and sampled downwind to measure dispersal and dilution factors under varying meteorological conditions. At least nine experiments (releases) will be conducted under a wide range of release and environmental situations so that diffusion parameters can be evaluated for all probable meteorological conditions (except precipitation) of release of radioactive aerosol and particulates to the atmosphere. Meteorological measurements over the test will be provided by the Atmospheric Physics Facility (NARF Item 33) and the Reactor Operations meteorological tower.

TEST PLAN

To establish base-line data for the parametric study, nine releases will be made at five feet above the base level of the Area 1 meteorological tower, near the two reactors. The tests are designed to provide data to evaluate the diffusion of radioactive aerosols released at a height where maximum concentration downwind can be expected. If project funding permits, the tests will be extended to study the effect of stack height, stack exhaust flow rate, and exhaust temperature.

As the tests are weather-dependent, there may be occasions of delays and aborts which will consume manpower time. Should these occurrences be minimal, time may be available for performing some of the additional tests.

The aerosol will be released to the atmosphere over a sampling array consisting of 121 low-volume samplers positioned on four arcs at 88, 176, 352, and 704 meters downwind. The arcs subtend a 60-degree angle with the centerline running north-south (see Fig. 11). The orientation is such that northerly winds will be required for a release condition. The surface, out to the 352-meter arc, is fairly level and consists of

grass and concrete pavement. Between the 352- and 704-m arcs, the surface is mostly concrete, with three buildings which will cause eddy effects and modification of the air stream.

The nine tests to be conducted are:

Two Releases	- Under moderately stable or neutral conditions where $-1^{\circ}C \leq (t_1 - t_{32}) \leq 1^{\circ}C$ and the winds are 6 to 12 mph.
Three Releases	- Under highly stable (inversion) conditions where $(t_1 - t_{32}) \leq -3^{\circ}C$ and the winds are less than 8 mph.
One Release	- Under unstable conditions (strong lapse) where $(t_1 - t_{32}) \geq 3^{\circ}C$ and the winds are 10 to 20 mph.
Three Releases	- Under meteorological conditions as may be prescribed from a study of previous releases.

No releases will be made during precipitation in the form of rain or snow. It may be possible to conduct a test during a fog, an extremely hazardous (meteorological) condition for the immediate area about the source.

TASK I - AEROSOL GENERATION

The uranine dye will be released to the atmosphere in solution by means of a paint spray gun. The air pressure will be adjuste to produce liquid droplets as small as possible. Previous use of this device has shown that it produces a fine spray and that evaporation of the water takes place before any significant settling occurs. The evaporative process is retarded significantly when the moisture content of the air exceeds 85% (relativ humidity). The uranine particles which result are small enough to constitute a true aerosol, mainly in the 1- to 10-micron range. The concentration of the uranine solution will be on the order of 10 gm/liter. It is expected that from 2 to 4 liters will be required for each release. Tests are currently underway to determine the optimum conditions for aerosol generation.

TASK II - SAMPLING OPERATION

The sampling array will be surveyed and electrical power distributed to each of 31 aerosol samplers positioned along the four arcs concentric about the release point at radii of 88, 176, 352, and 704 m. These samplers will be running continuously during passage of the fluorescent effluent cloud.

The sampler to be used will be the Gelman Bantam, which has a flow rate of 1.5 cfm. This unit operates on 110 v-ac, weighs 8 lb, has dimensions of 9 x 5 x 4.5 in., and is supplied with a 2-in. open face filter holder. The latter will be mounted near the top of a 5-ft stanchion and connected to the sampler pumping unit by means of latex tubing. During a test operation the sampling unit will be placed on the base of the portable stanchion, which consists of a 5-ft, 1-in. angle-iron held in a vertical position by a 35-lb concrete base. Four 25-ft stanchions will be positioned on the 704-m arc to permit sampling above the roofline of an intervening structure.

Electric power will be supplied to each unit through a cable placed on the ground (or concrete pavement) along the four arcs. The power distribution equipment will be portable to accommodate traffic passage, periods of non-testing, and variation in orientation of the sampling array. Receptacles (110-v-ac outlet) will be provided at each sampling station. The Bantam motor draws 2 amp of electrical current (see Figure 11).

In addition to the 121 electrical outlets distributed along the four arcs, six receptacles will be provided on each of the 88- and 176-m arcs to supply power to 12 more Bantam units to be used with Casella and Andersen impactor-type samplers. Master switches will be provided for controlling the "on-off" electric power to the samplers.

TASK III - METEOROLOGICAL MEASUREMENTS

Wind and temperature profiles will be made at the Atmospheric Physics Facility (TATR Hill) at Reactor Operations, Area 1. The APF tower measurements will include air temperature at 1, 2, 4, 8, 16, and 32 m above the surface; wind speeds at 2, 4, 16, and 32 m; wind direction at 4 and 32 m; net radiation at 2 m; and air turbulence (bivane measurements) at 2 m.

Nuclear Operations tower measurements will include wind speed and direction at 12 m, temperature at 2 m, and temperature differential between 2 and 12 m.

Meteorological measurements will be automatically recorded on strip charts.

Weather forecast service will be provided through the facility of the Air Force (AWS) weather detachment at Carswell AFB. Forecast information is essential to scheduling of a test event.

TASK IV - SAMPLE ASSAY

After an aerosol release, all filter holders will be capped and removed from the stanchion and taken to the Nuclear Laboratory for analysis. Uranine is water soluble, and removal from the filter will be accomplished by washing in a measured volume of distilled water in an ultrasonic field. Tests have shown that release of uranine from the Gelman AM-4 filter is essentially 100%. The resulting water solution will be assayed with a fluorometer to determine the amount of uranine collected by the filter. The sample analysis will be handled by the Nuclear Laboratory.

The samples obtained by the impactors will be examined under the microscope to determined the particle sizes. The particulate study will be documented by photomicrography. The uranine particulates will be put into solution and assayed using the fluorometer to obtain quantitative data for particle-size study.

TASK V - DATA REDUCTION AND ANALYSIS

The quantitative determinations resulting from the sample assays will be used to compute the uranine concentration in the air at each sampling station over the array. Isopleths of concentration will be plotted to show graphically the distribution of fluorescent aerosol downwind of the release point. From these data, dilution factors will be computed and correlated with meteorological conditions (wind speed, lapse rate, temperature, humidity, air stability from bivane data, wind variability, and net radiation) obtained from the Atmospheric Physics Facility and the Reactor Operations meteorological tower.

The aerosol concentration data will be used to ascertain NARF diffusion parameters appropriate for the general statistical diffusion equation. With the execution of tests as planned, it is expected that parametric values will be obtained for a wide span of atmospheric situations ranging from strong inversion to strong lapse conditions.

TASK VI - REPORT

A report including the installation, operation, data obtained, analysis, and results will be written covering the NARF Diffusion Tests.

APPENDIX B

DIFFUSION TEST EQUIPMENT USED IN NARF AREA

Item	Quantity Required	Description
Test Trailer	1	Storage, test-staging test equipment, and sampler processing
Atmospheric Physics Facility	1	Meteorological measurements for test support NARF Item 33
Electric Power Distribution	1	110 v-ac, 60 cycle to 4 arcs on 60° spread at 88, 176, 352, 704 m from release point
Stanchion	117	5-ft angle iron mounted in concrete for sampler support
Stanchion	4	25-ft aluminum tube insert in pipe in ground for filter head mount
Network Survey	4 arcs	31 sampler stations on each of the 4 arcs
Sampler, Pumping Unit	132	Gelman Bantam sampler, 110 v-ac, 60 cycle, 2-amp, 1.5 cfm
Casella Sampler	12	4-stage impactor with filter back-up; 6 units per test
Andersen Sampler	12	5-stage impactor with in-line filter back-up; 6 units per test
Filter Holder	234	Gelman, 2-in. Al open face w/cap
Tubing (Hose)	500 ft 100 ft	Latex, 4-ft lengths Latex, 25-ft lengths
Filter	1200	Gelman, 2-in. membrane, AM-4
Aerosol	1/2 lb	Fluorescein (uranine dye)
Aerosol Dispenser	2	Spray gun, w/2-liter reservoir, air hose, and tripod mount
Assay Meter	1	Fluorometer (GD/FW)

APPENDIX C

AEROSOL PRODUCTION AND SIZING

A review is presented of recent work done on NARF Item 34 in the area of particle sizing of an airborne aerosol, a uranir water solution. By means of photomicrography, samples of aspir uranine-dye solution are shown as droplets or particles collect on glass plates of Unico and Andersen impactors.

The tests were performed to (1) measure particle sizes of the aerosol collected downwind and (2) determine the best technique for aerosol generation.

C-1 Aerosol Generation

A paint spray gun with a 2-liter reservoir was employed to "atomize" the water solution of the fluorescent dye and to dispense the spray at a 5-ft level to the atmosphere. Samplers to trap the tracer aerosol were located at measured distances downwind. After each run, the plates of the impactor were viewed with the Pathostar microscope and photographed with an attached Polaroid camera.

Difficulties were experienced in attempting to collect a "dry" aerosol of discrete uranine particles; agglomeration of solution droplets in the air and on the glass plates is evident in most of the photographs. To produce satisfactory results, i.e., samples of dry particles, the following con-

ditions were found to be necessary:

1. Maximum air pressure (40 psig) in dispenser.
2. Relative humidity less than 50%.
3. Wind speed of 7 - 15 mph.
4. Temperature above 60°F.
5. Sampler 100 ft (or more) downwind.

C-2 Aerosol Sampling

Development work on tracers applicable to general meteorological work should be guided by the standards set up by Hemeon and Haines (Industrial Hygiene Foundation). They require that the sampling instruments be simple, low in cost, and automatic and, in addition, that the analysis of the sample be significantly less laborious than the counting technique required by the particulate tracer materials. In addition, various experiences with tracer tests have indicated that an ideal tracer material should have the following characteristics:

1. Be easy to detect.
2. Be easy to disperse.
3. Be nontoxic.
4. Have a distinctive property (to avoid confusion with other airborne materials).
5. Be low to moderate in cost.
6. Be readily adaptable to field working conditions.

Uranine dye rates high in each of these characteristics. The important consideration here is to disperse the tracer

under conditions which favor the formation of uranine particles quickly. All tracers have these properties to various degrees. Recent experience at Stanford Research Institute has shown that uranine dye has all of these attributes and with respect to low cost and adaptability to field conditions, appears to be superior to the other available tracers.

C-3 Nature of Uranine Dye

Uranine is a commercial dye-stuff available from several manufacturers under various trade names. It is the di-sodium salt of fluorescein and is familiar as a sea-marker in air-sea rescue work. Uranine is nontoxic and is an accepted USFDA food color used in a variety of ways. Its usefulness as an atmospheric tracer lies in the fact that extremely minute amounts of it may be quantitatively measured with relatively simple techniques. A water solution of uranine is greenish-yellow in ordinary light. The solution absorbs blue light in the 4400-5200 A region and has a very strong fluorescence in the yellow-green between 5100 and 5900 A.

C-4 Uranine Assay

Light from a mercury-vapor lamp (GE Type BLB, 6-w), filtered through a Kodak Wratten Filter No. 47 (dark blue), is fluorescence of a sample solution. The amount of fluorescence is determined by the output of a photomultiplier tube (RCA Type 5819) set at right angles to the primary beam. The influence of scattered primary light is minimized by a

Wratten Filter No. 15 (light yellow) located in the path of the emitted fluorescent light. The current produced is measured by a micromicroammeter (GD/FW Model MA-2) using a Fluke power supply at a setting of 800 v.

The response of the system is a linear function of uranine concentration for solutions with concentrations less than about 10^{-6} gm/ml. With this system and the sample cell, which holds 10 ml of solution, it is possible to get a full-scale deflection of the instrument with uranine solution concentrations of 10^{-7} gm/ml. Since meter readings can easily be made to less than 1% of full scale, the precision of measurement is better than 10^{-9} gm/ml. If the minimum detectability is considered to be one scale division on the 0-100 meter, then the minimum detectable uranine concentration is 10^{-9} gm/ml.

In the experimental work that was done, the uranine samples were dispersed in 10 ml of distilled water for analysis. Thus, full-scale deflection of the meter corresponded to a total sample of 10^{-6} gm of uranine and the minimum detectable sample was 10^{-8} gm. This weight is equivalent to that of a single particle of uranine 10 microns in diameter. This performance is equal to that attainable with any other tracer technique currently known to be used for general aerosol releases, with the exception of some radioactive tracer techniques.

C-5 Dispersion of the Tracer Aerosol

In order to be used as a tracer, the uranine must be dispersed into the air and its particles must be so small

that they will experience negligible settling in the time interval of the experiment. In the current tracer work, the maximum time required for the tracer to be carried across the sampling area was about 7 minutes. In this time, a 6-micron dry particle of dye would settle about 3 ft and smaller particles would settle to a lesser extent. This is a relatively small amount compared with the motion produced by mixing currents and turbulence which are also acting on the aerosol. Thus, the tracer aerosol should follow the air motion in the desired fashion as long as the particles are small enough, and the task of dispersing the tracer becomes one of generating small-sized particles in such a manner that detectable amounts of material can be dispersed in the time interval available.

Dispersal of the uranine dye was carried out by spraying a solution of the dye into the air, using a DeVilbis paint sprayer under 40 psig of air pressure (Figs. C-1 and C-2). The liquid aerosol droplets from the nozzle dried rapidly in the air when the relative humidity was less than 50%. When the moisture content of the air was 80% or more, the evaporative process was significantly retarded so that some liquid droplets were collected 35 m downwind. The size distribution of uranine particles dispersed in this manner is dependent upon the concentration of dye in the spray solution, the air pressure applied to the nozzle, the liquid flow rate through the nozzle, and the relative humidity of the atmosphere

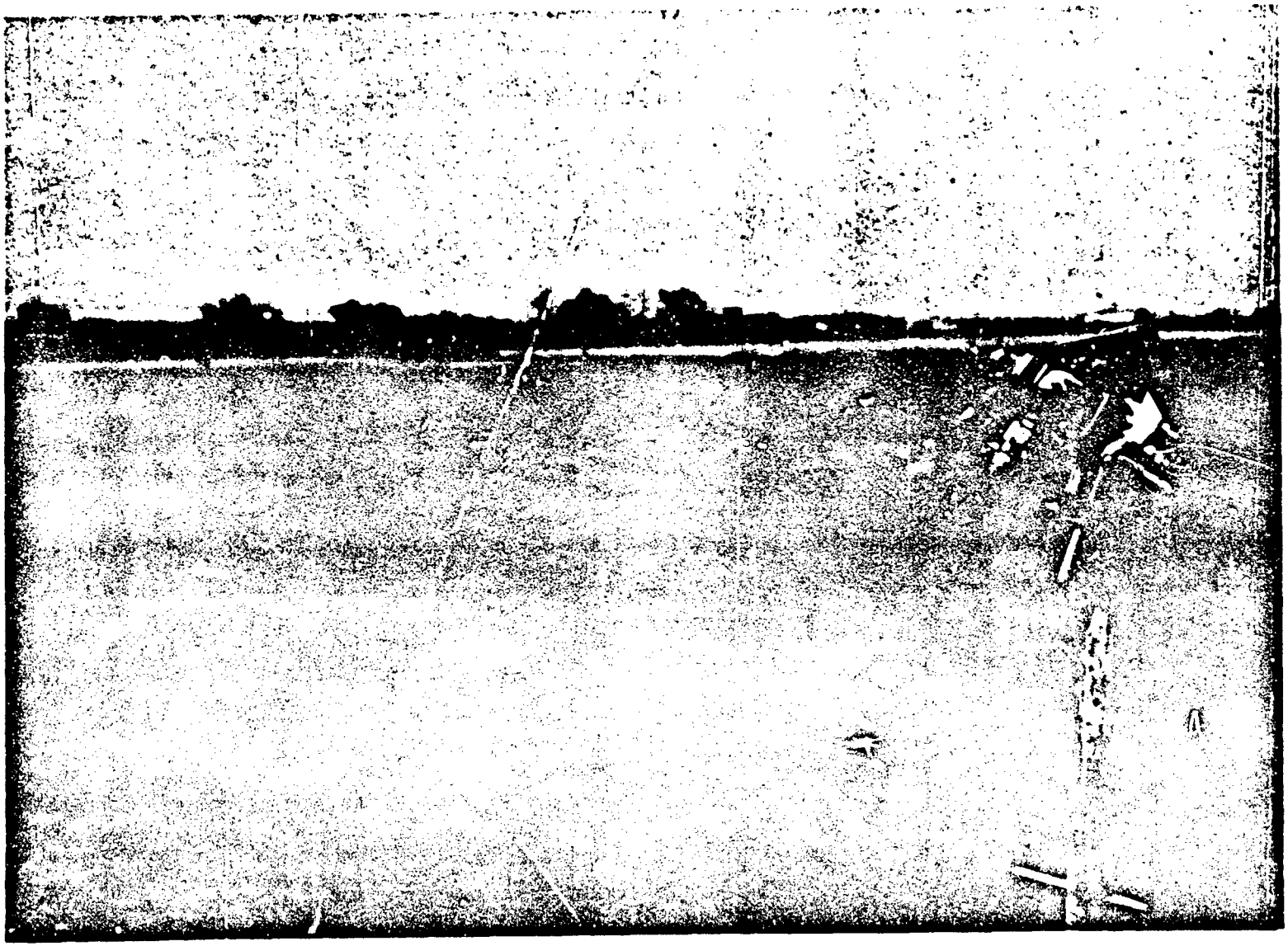


Figure C-1 Paint Spray Gun Releasing Uranine Mist to Atmosphere

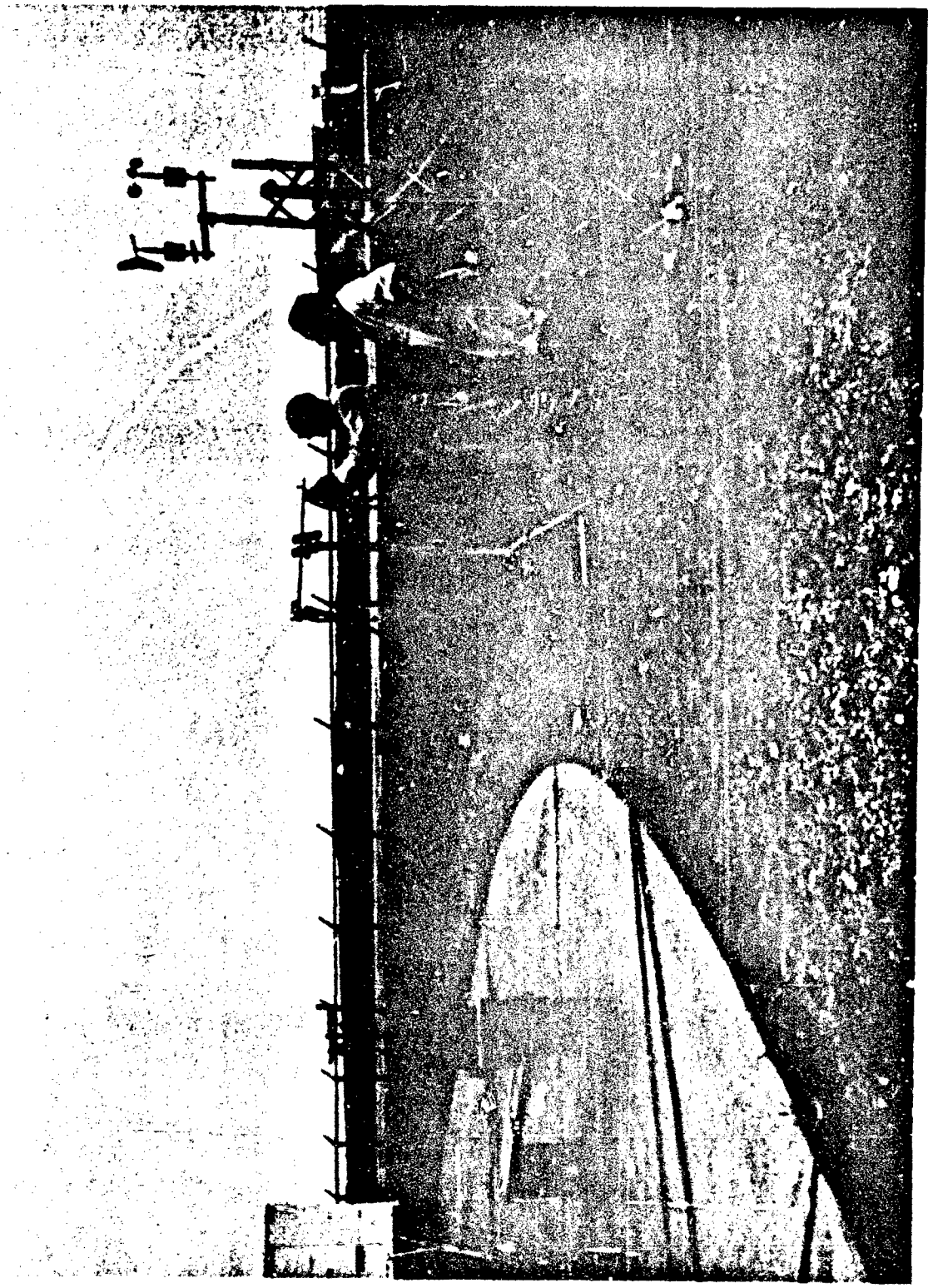


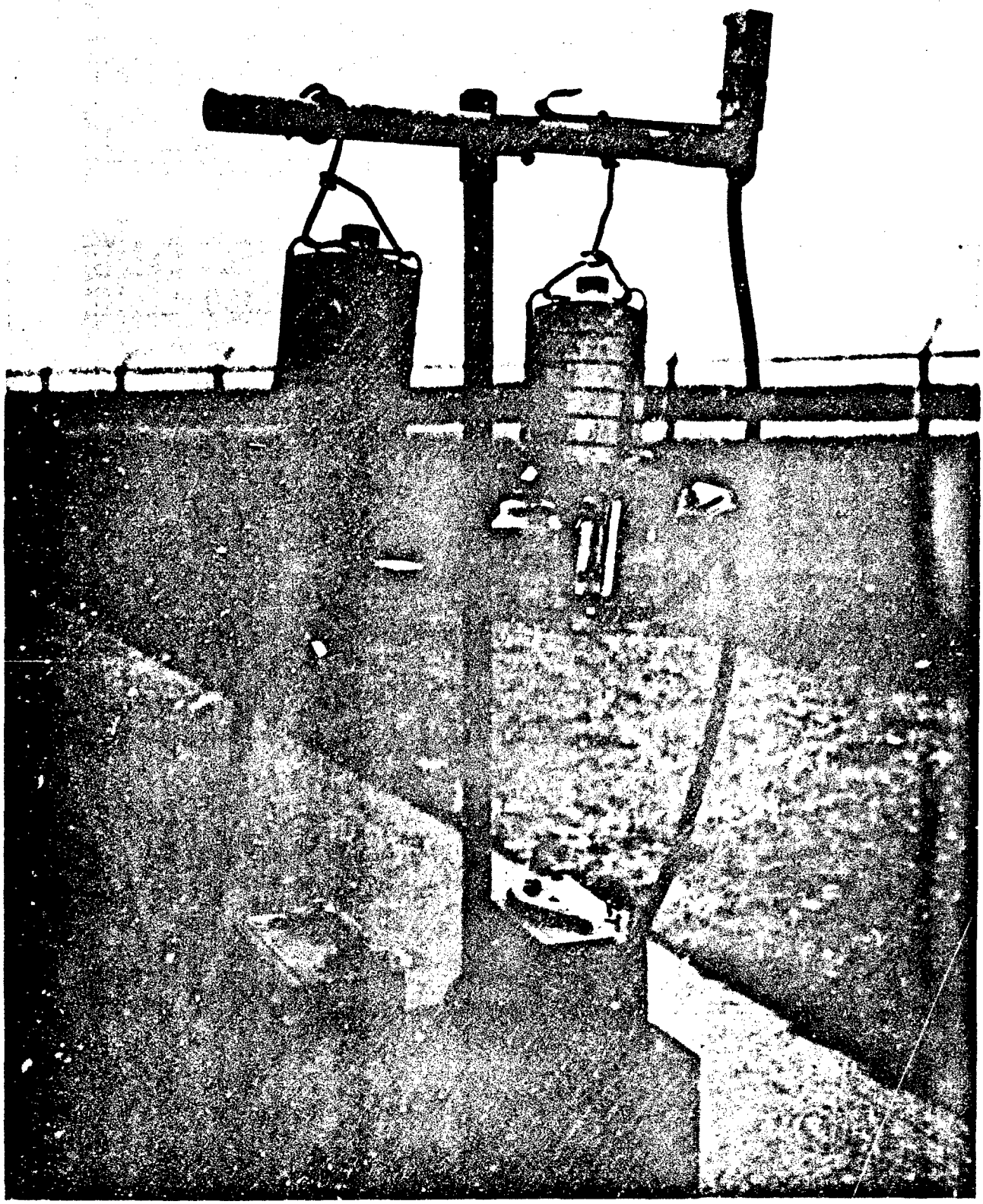
Figure 5-2 Aerosol Generation and Sampling

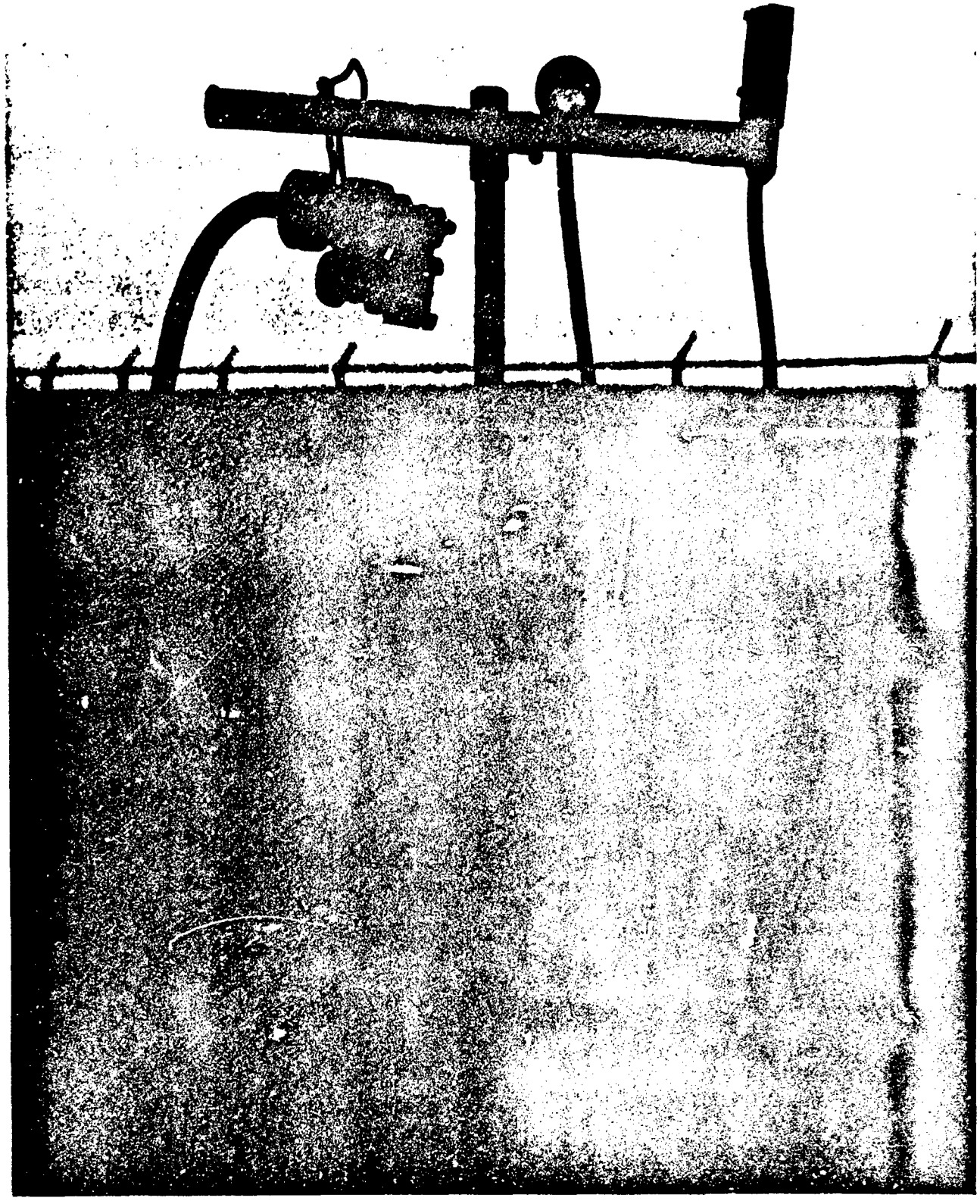
into which the uranine is released.

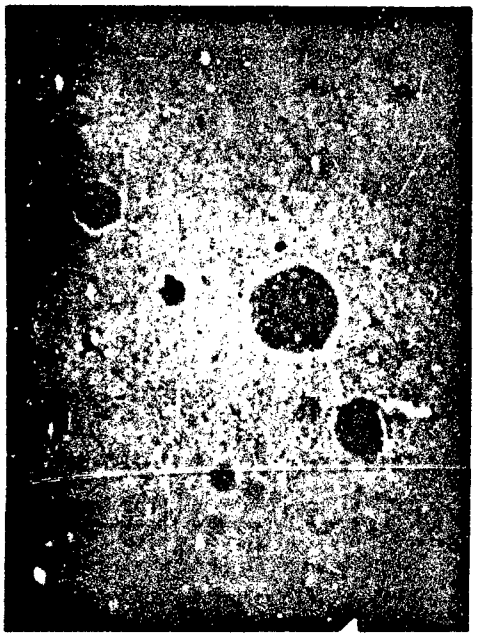
C-6 Particulate Sizing

The sizing of the dispersed uranine particles was accomplished with the Andersen, Casella, and Unico impactor-type samplers. These instruments are shown in Figures C-3 and C-4. The collected samples were observed with a Pathostar microscope at various magnifications up to x970. Photographs of the sample particles, as seen under the microscope, were taken with a Polaroid camera. Some of the photographs are shown in Figures C-5 and C-6.

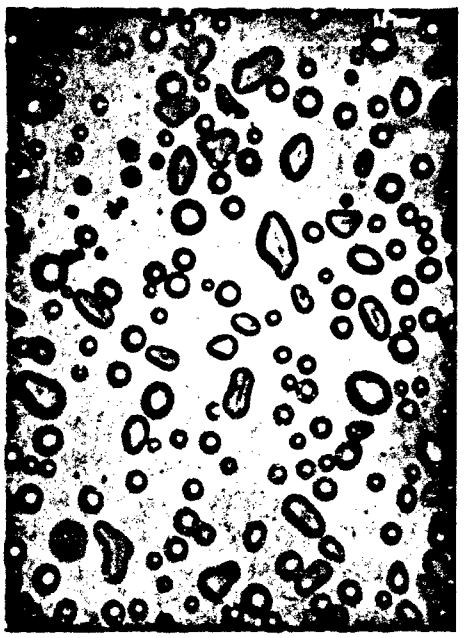
The uranine samples collected on the plates of the Casella and Andersen impactors were analyzed by the fluorometer to give a quantitative evaluation of particulate size. Using the calibration data previously obtained for each of the samplers, and the calibration curve (Fig. C-7) for the fluorometer, a particle size distribution was obtained for the dispersed uranine. Samples of the dye were collected by the Andersen and Casella impactors during Tests 1 and 3 for the purpose of measuring the particulate sizes of airborne uranine at from 88 to 176 m downwind. The results of this determination are shown in Figure C-8.





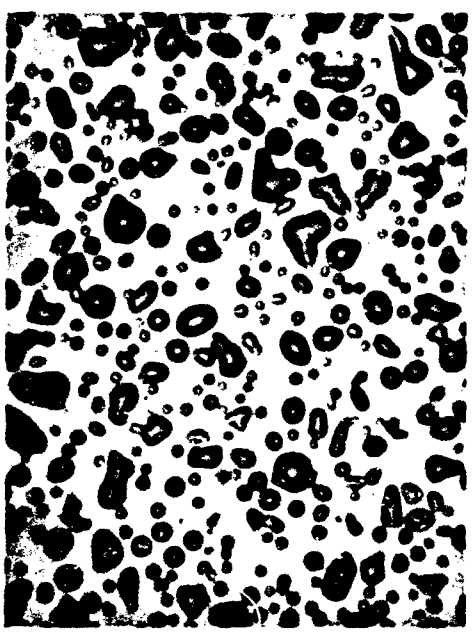


Stage 1 X 430

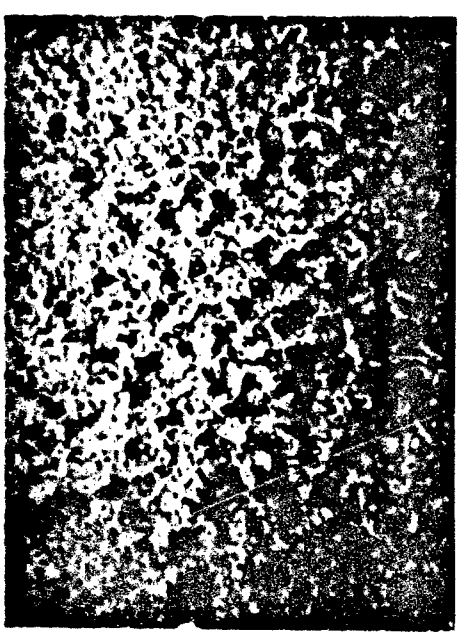


Stage 2 X 430

100 Microns

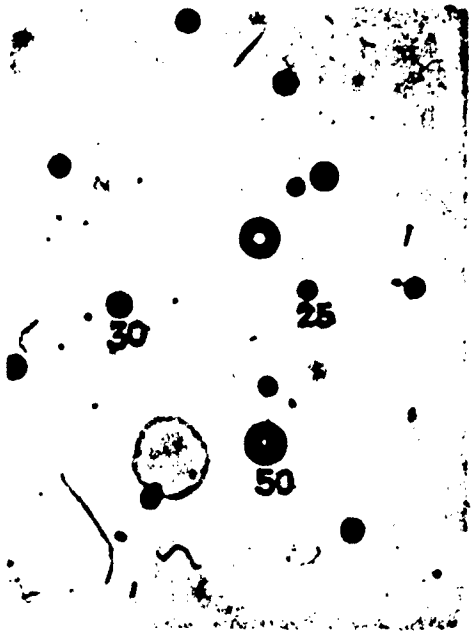


Stage 3 X 430



Stage 4 X 430

Figure C-5. Photographs of Uranine Particles Collected by Casella Impactor

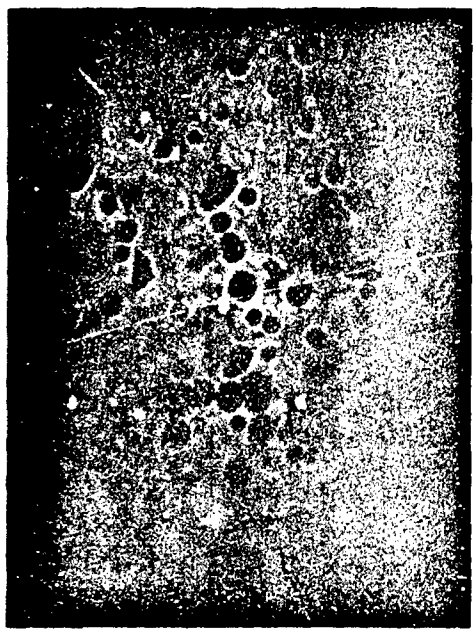


Stage 2 X 100

0 100 200 Microns

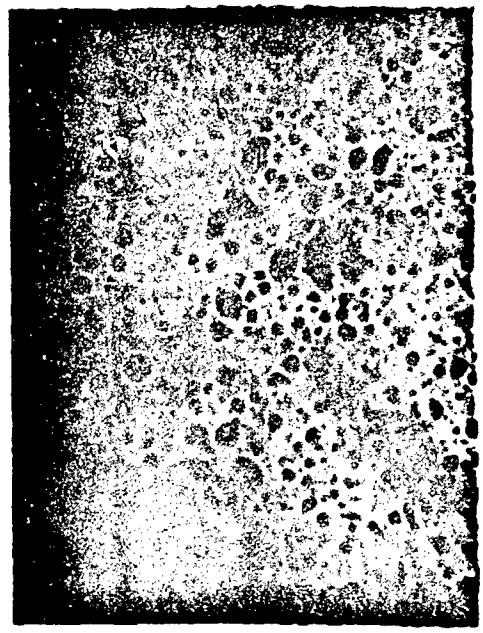
Stage 3 X 430

0 50 Microns



Stage 4 X 430

0 50 Microns



Stage 5 X 970

0 25 Microns

Figure C-6. Photographs of Uranine Particles Collected by Andersen Sampler

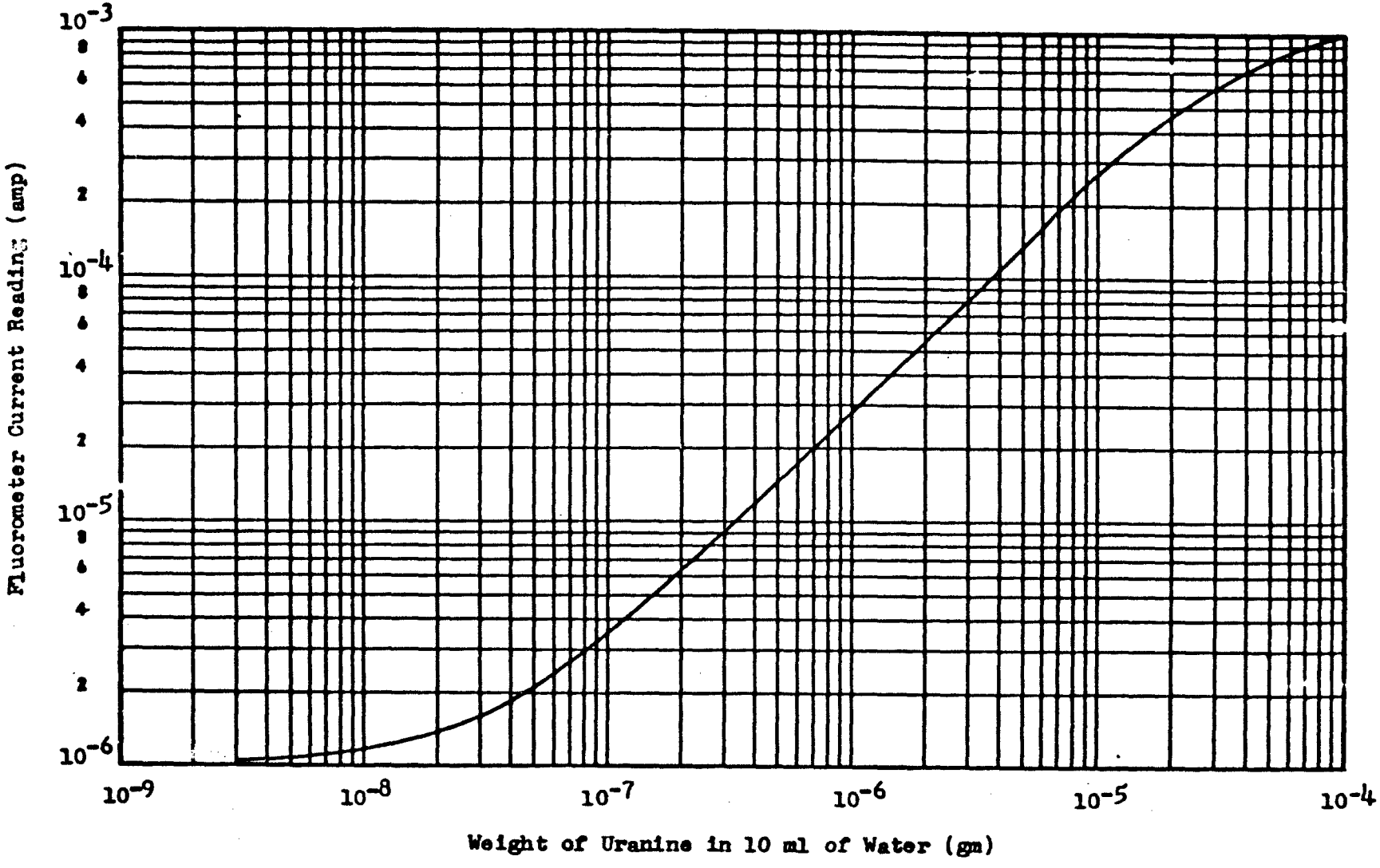


Figure C-7 Fluorometer Calibration Curve

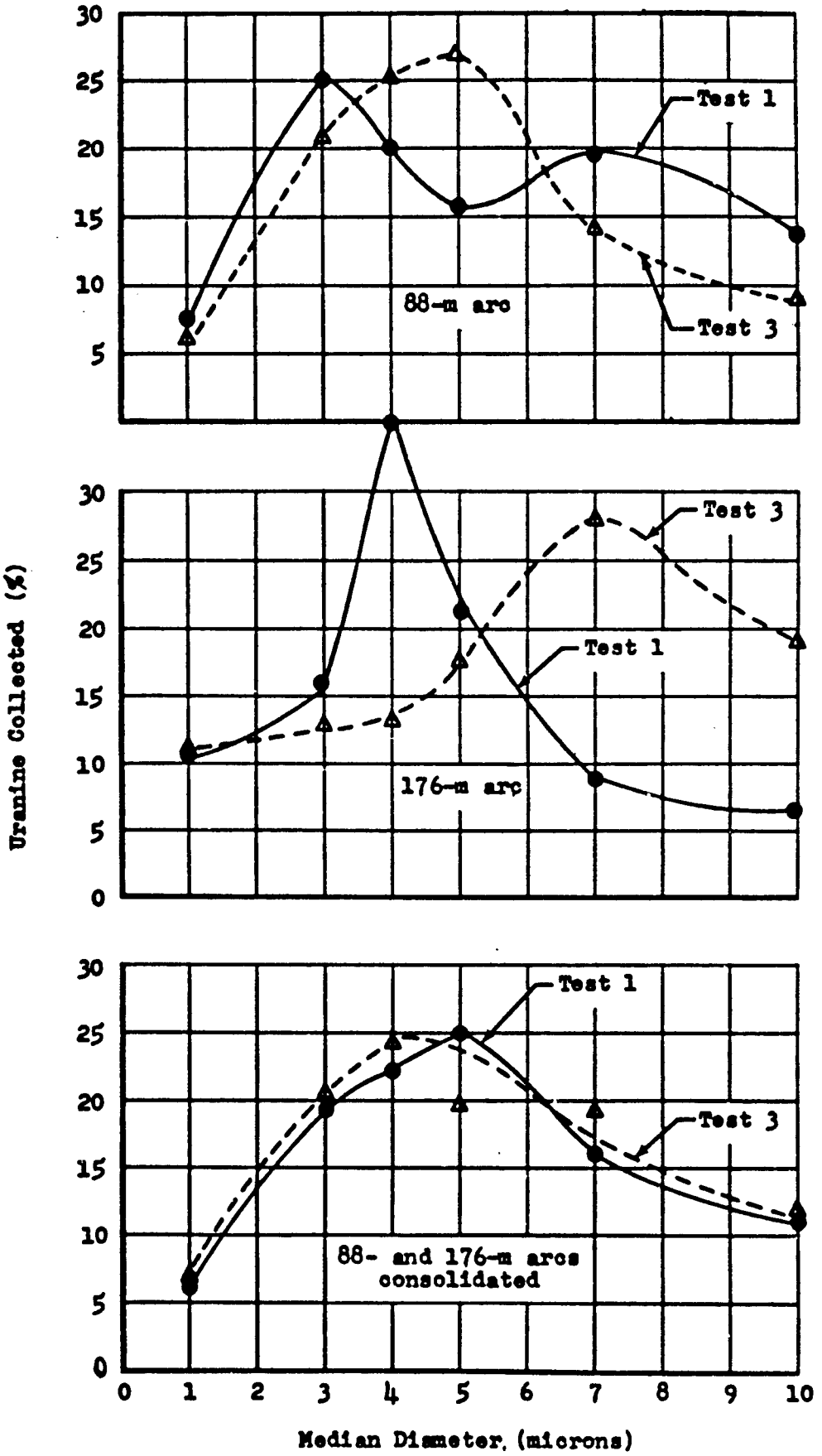


Figure C-8 Uranine Particle Size Distribution for Tests 1 and 3

APPENDIX D

DIFFUSION TEST DATA

This appendix contains the basic data taken at the NARF site during diffusion test operations.

Tables D-1 through D-4 give the measurements obtained on the quantitative low-volume sampling of uranine effluent in Tests 1 through 4. Tables D-5 and D-6 give the data collect on particulate sizing in Tests 1 and 3 by the Casella and Andersen impactors at the 88- and 176-m arcs. Table D-7 gives a comparison of the cloud concentrations at the 5- and 25-ft elevations above the 704-m arc.

Figure D-1 shows the mean temperature profiles for the four tests and the profile at the time of each release; these measurements were made at six levels between 1 and 32 m above the ground. Figure D-2 shows the wind direction and velocity occurring during the 35-min intervals of the four test periods; these measurements were taken at 4 m above the ground.

Table D-1

DIFFUSION TEST SAMPLE DATA FOR TEST 1

Test No. 1 Type: Lapse Time of Day: 1543-1556 27 January 1964

Source: Uranine Source Quantity: 40 grams in 4 liters of water

Air-Sample-Filter Data

Station No.	Radial (deg)	Arc A, 88m Flow Rate (cfm)	Arc A, 88m Fluor Rdg (μa)	Arc A, 88m Sample Wt (10^{-8}gm)	Arc B, 176m Flow Rate (cfm)	Arc B, 176m Fluor Rdg (μa)	Arc B, 176m Sample Wt (10^{-8}gm)	Arc C, 352m Flow Rate (cfm)	Arc C, 352m Fluor Rdg (μa)	Arc C, 352m Sample Wt (10^{-8}gm)	Arc D, 704m Flow Rate (cfm)	Arc D, 704m Fluor Rdg (μa)	Arc D, 704m Sample Wt (10^{-8}gm)
1	330	0.60	1.0	--	0.60	1.1	--	0.62	1.4	2.2	--	--	--
2	332	0.60	1.1	--	0.60	1.5	2.5	0.65	1.3	1.5	--	--	--
3	334	0.60	1.1	--	0.60	1.0	--	0.62	1.2	1.0	--	--	--
4	336	0.60	1.2	1.0	0.60	1.0	--	0.60	1.2	1.0	--	--	--
5	338	0.60	1.4	2.2	0.60	1.3	1.5	0.62	1.2	1.0	0.60	2.5	7.0
6	340	0.60	1.4	2.2	0.60	--	--	0.60	1.4	2.2	0.60	2.9	8.8
7	342	--	3.7	12.0	0.60	1.6	3.1	0.56	1.5	2.6	0.60	1.98	4.8
8	344	0.60	4.1	13.5	0.60	1.9	4.4	0.60	1.9	4.4	0.60	2.2	5.8
9	346	0.49	4.1	13.5	0.60	1.8	4.0	0.61	2.4	6.6	0.60	1.78	3.9
10	348	0.60	9.5	33.0	0.60	3.8	12.5	--	--	--	0.60	1.4	2.2
11	350	0.60	6.7	23.0	0.60	3.3	10.5	0.56	2.9	8.8	0.60	1.6	3.0
12	352	0.60	15.0	52.0	0.60	3.4	11.0	0.58	1.8	4.0	0.60	1.4	2.2

Table D-1 (Cont'd)

Air-Sample-Filter Data

Station No.	Radial (deg)	Arc A, 88m Flow Rate (cfm)	Arc A, 88m Fluor Rdg (μa)	Arc A, 88m Sample Wt (10^{-8}gm)	Arc B, 176m Flow Rate (cfm)	Arc B, 176m Fluor Rdg (μa)	Arc B, 176m Sample Wt (10^{-8}gm)	Arc C, 352m Flow Rate (cfm)	Arc C, 352m Fluor Rdg (μa)	Arc C, 352m Sample Wt (10^{-8}gm)	Arc D, 704m Flow Rate (cfm)	Arc D, 704m Fluor Rdg (μa)	Arc D, 704m Sample Wt (10^{-8}gm)
13	354	0.60	13.0	46.0	0.60	2.3	6.3	0.58	1.9	4.4	0.60	1.0	--
14	356	0.59	12.0	42.0	0.60	1.2	1.0	0.59	1.8	4.0	0.60	1.0	--
15	358	0.60	19.0	67.0	0.60	2.8	8.3	0.51	2.6	7.4	0.60	1.3	1.6
16	360	0.60	14.0	50.0	0.60	2.5	7.0	0.58	2.6	7.4	0.60	1.1	--
17	002	0.60	9.6	33.0	0.60	1.8	4.0	0.62	2.0	4.8	0.60	1.1	--
18	004	0.60	5.8	20.0	0.60	2.3	6.3	0.60	1.5	2.6	0.60	1.0	--
19	006	0.60	7.7	26.5	0.60	2.0	4.8	0.60	1.4	2.2	0.60	1.0	--
20	008	0.60	6.2	21.5	0.60	1.0	--	0.60	1.5	2.6	0.60	1.2	1.0
21	010	0.60	2.6	7.4	0.60	1.2	1.0	0.53	1.0	--	0.60	1.2	1.0
22	012	0.60	1.8	4.0	0.60	1.1	--	0.60	1.1	--	0.60	1.3	1.6
23	014	0.60	1.9	4.4	0.60	1.0	--	0.60	1.0	--	0.60	1.1	--
24	016	0.60	1.2	1.0	0.60	1.0	--	0.60	1.0	--	0.60	1.1	--
25	018	0.60	1.2	1.0	0.60	1.0	--	0.60	1.1	--	0.60	1.1	--
26	020	0.60	1.0	--	0.60	1.1	--	0.56	1.0	--	0.60	1.2	1.0
27	022	0.60	1.0	--	0.60	1.0	--	0.60	1.0	--	0.60	1.1	--
28	024	0.60	1.1	--	0.60	1.0	--	0.60	1.0	--	0.60	1.0	--
29	026	0.60	1.0	--	0.60	1.0	--	0.60	1.0	--	--	--	--
30	028	0.60	1.0	--	0.60	1.1	--	0.60	1.0	--	--	--	--
31	030	0.60	1.1	--	0.60	1.0	--	0.60	1.0	--	--	--	--

Table D-2

DIFFUSION TEST SAMPLE DATA FOR TEST 2

Test No. 2 Type: Lapse Time of Day: 1543-1556 27 January 1954

Source: Uranine Source Quantity: 40 grams in 4 liters of water

Air-Sample-Filter Data

Station No.	Radial (deg)	Arc A, 88m Flow Rate (cfm)	Arc A, 88m Fluor Rdg (μa)	Arc A, 88m Sample wt (10^{-8}gm)	Arc B, 176m Flow Rate (cfm)	Arc B, 176m Fluor Rdg (μa)	Arc B, 176m Sample wt (10^{-8}gm)	Arc C, 352m Flow Rate (cfm)	Arc C, 352m Fluor Rdg (μa)	Arc C, 352m Sample wt (10^{-8}gm)	Arc D, 704m Flow Rate (cfm)	Arc D, 704m Fluor Rdg (μa)	Arc D, 704m Sample wt (10^{-8}gm)
1	330	0.60	1.0	--	0.60	--	--	0.62	--	--	--	--	--
2	332	0.60	--	--	0.60	--	--	0.65	--	--	--	--	--
3	334	0.60	1.0	--	0.60	--	--	0.62	1.0	--	--	--	--
4	336	0.60	--	--	0.60	1.4	2.2	0.60	--	--	--	--	--
5	338	0.60	--	--	0.60	--	--	0.62	1.0	--	0.60	1.0	--
6	340	0.60	1.0	--	0.60	1.2	1.0	0.60	1.0	--	0.60	--	--
7	342	0.60	1.0	--	0.60	--	--	0.56	--	--	0.60	1.0	--
8	344	0.60	--	--	0.60	--	--	0.60	--	--	0.60	--	--
9	346	0.49	--	--	0.60	--	--	0.01	--	--	0.60	--	--
10	348	0.60	--	--	0.60	--	--	0.58	--	--	0.60	--	--
11	350	0.60	1.0	--	0.60	--	--	0.60	--	--	0.60	--	--
12	352	0.60	1.2	1.0	0.60	--	--	0.58	--	--	0.60	--	--

Table D-2 (Cont'd)

Air-Sample-Filter Data

Station No.	Radial (deg)	Arc A, 88m Flow Rate (cfm)	Arc A, 88m Fluor Rdg (μa)	Arc A, 88m Sample Wt (10^{-8}gm)	Arc B, 176m Flow Rate (cfm)	Arc B, 176m Fluor Rdg (μa)	Arc B, 176m Sample Wt (10^{-8}gm)	Arc C, 352m Flow Rate (cfm)	Arc C, 352m Fluor Rdg (μa)	Arc C, 352m Sample Wt (10^{-8}gm)	Arc D, 704m Flow Rate (cfm)	Arc D, 704m Fluor Rdg (μa)	Arc D, 704m Sample Wt (10^{-8}gm)
13	354	0.60	1.5	2.6	0.60	--	--	0.58	--	--	0.60	--	--
14	356	0.59	1.6	3.0	0.60	--	--	0.59	--	--	0.60	--	--
15	358	0.60	2.0	4.8	0.60	1.2	1.0	0.51	--	--	0.60	--	--
16	360	0.60	6.3	21.5	0.60	1.4	2.2	0.58	1.0	--	0.60	--	--
17	002	0.60	4.4	14.5	0.60	3.4	10.5	0.62	1.0	--	0.60	--	--
18	004	0.60	6.6	22.5	0.60	3.4	10.5	0.60	1.3	15.0	0.60	1.0	--
19	006	0.60	3.9	12.5	0.60	3.7	12.0	0.60	1.0	--	0.60	--	--
20	008	0.60	9.0	31.0	0.60	4.3	14.0	0.60	1.4	22.0	0.60	1.0	--
21	010	0.60	6.0	21.0	0.60	1.7	3.5	0.53	1.2	10.0	0.60	1.0	--
22	012	0.60	7.5	26.0	0.60	1.8	4.0	0.60	1.5	26.0	0.60	--	--
23	014	0.60	3.1	9.6	0.60	2.0	4.8	0.60	1.4	22.0	0.60	--	--
24	016	0.60	2.9	8.8	0.60	1.1	--	0.60	1.3	15.0	0.60	1.0	--
25	018	0.60	3.7	10.0	0.60	1.6	3.0	0.60	1.0	--	0.60	--	--
26	020	0.60	2.2	5.8	0.60	1.0	--	0.56	--	--	0.60	--	--
27	022	0.60	1.4	2.2	0.60	1.2	1.0	0.60	1.0	--	0.60	--	--
28	024	0.60	1.2	1.0	0.60	1.2	1.0	0.60	--	--	0.60	--	--
29	026	0.60	1.2	1.0	0.60	--	--	0.60	1.0	--	--	--	--
30	028	0.60	1.1	--	0.60	1.0	--	0.60	1.0	--	--	--	--
31	030	0.60	1.0	--	0.60	--	--	0.60	1.0	--	--	--	--

Table D-3

DIFFUSION TEST SAMPLE DATA FOR TEST 3

Test No. 3 Type: Mild Lapse Time of Day: 0930-0946 21 February 1964

Source: Uranine Source Quantity: 200 grams in 4 liters of water

Air-Sample-Filter Data

Station No.	Radial (deg)	Arc A, 88m			Arc B, 176m			Arc C, 352m			Arc D, 704m		
		Flow Rate (cfm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)	Flow Rate (cfm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)	Flow Rate (cfm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)	Flow Rate (cfm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)
1	330	0.60	1.2	1.0	0.60	1.8	4.0	0.60	1.1	--	--	--	--
2	332	0.60	1.2	1.0	0.60	1.9	4.4	0.60	1.0	--	--	--	--
3	334	0.60	1.1	--	0.60	1.6	3.2	0.60	1.4	2.2	--	--	--
4	336	0.60	1.1	--	0.60	1.2	1.0	0.60	1.1	--	--	--	--
5	338	0.60	1.1	--	0.60	1.1	--	0.60	1.2	1.0	0.60	1.2	1.0
6	340	0.60	1.2	1.0	0.60	1.1	--	0.60	1.1	--	0.60	1.0	--
7	342	0.60	1.1	--	0.60	1.3	1.6	0.60	1.1	--	0.60	1.1	--
8	344	0.60	1.2	1.0	0.60	1.1	--	0.60	1.0	--	0.60	1.0	--
9	346	0.60	1.4	2.2	0.60	1.1	--	0.60	1.1	--	0.60	1.0	--
10	348	0.60	1.8	4.0	0.60	1.1	--	0.60	1.0	--	0.60	1.0	--
11	350	0.60	5.7	20.0	0.60	1.7	3.5	0.60	1.1	--	0.60	1.1	--
12	352	0.60	13.0	46.0	0.60	1.4	2.2	0.60	1.2	1.0	0.60	1.2	1.0

Table D-3 (Cont'd)

Air-Sample-Filter Data

Station No.	Radial (deg)	Arc A, 88m Flow Rate (cfm)	Arc A, 88m Fluor Rdg (μa)	Arc A, 88m Sample Wt (10^{-8}gm)	Arc B, 176m Flow Rate (cfm)	Arc B, 176m Fluor Rdg (μa)	Arc B, 176m Sample Wt (10^{-8}gm)	Arc C, 352m Flow Rate (cfm)	Arc C, 352m Fluor Rdg (μa)	Arc C, 352m Sample Wt (10^{-8}gm)	Arc D, 704m Flow Rate (cfm)	Arc D, 704m Fluor Rdg (μa)	Arc D, 704m Sample Wt (10^{-8}gm)
13	354	0.60	19.0	67.0	0.60	1.5	2.6	0.60	1.4	2.2	0.60	1.2	1.0
14	356	0.60	30.0	108.0	0.60	1.5	2.6	0.60	1.5	2.5	0.60	1.1	--
15	358	0.60	40.0	145.0	0.60	1.5	2.6	0.60	1.8	4.0	0.60	1.0	--
16	360	0.60	49.0	180.0	0.60	1.7	3.5	0.60	2.3	6.2	0.60	1.4	2.2
17	002	0.60	86.0	320.0	0.60	2.7	7.8	0.60	1.6	3.2	0.60	1.2	1.0
18	004	0.60	87.0	325.0	0.60	8.3	29.0	0.60	3.5	11.0	0.60	1.4	2.2
19	006	0.60	68.0	250.0	0.60	16.0	57.0	0.60	3.1	9.6	0.60	1.4	2.2
20	008	0.60	48.0	175.0	0.60	5.7	20.0	0.60	3.6	11.5	0.60	2.0	4.8
21	010	0.60	61.0	225.0	0.60	14.0	50.0	0.60	3.0	9.2	0.60	2.7	7.8
22	012	0.60	44.0	160.0	0.60	14.0	50.0	0.60	4.4	14.5	0.60	1.5	2.6
23	014	0.60	54.0	200.0	0.60	5.4	18.5	0.60	4.3	14.0	0.60	2.9	9.0
24	016	0.60	37.0	135.0	0.60	1.6	3.2	0.60	3.3	10.0	0.60	1.6	3.1
25	018	0.60	40.0	145.0	0.60	1.7	3.5	0.60	3.2	9.9	0.60	1.4	2.2
26	020	0.60	27.0	96.0	0.60	1.4	2.2	0.57	2.9	9.0	0.60	1.1	--
27	022	0.60	14.0	50.0	0.60	1.6	3.2	0.60	2.7	7.8	0.60	1.0	--
28	024	0.60	4.9	18.0	0.60	1.3	1.6	0.57	1.8	4.0	0.60	1.1	--
29	026	0.60	5.4	18.5	0.60	1.4	2.2	0.60	1.4	2.2	--	--	--
30	028	0.60	3.6	11.5	0.60	1.3	1.6	0.60	1.0	--	--	--	--
31	030	0.60	2.3	6.2	0.60	1.2	1.0	0.60	1.0	--	--	--	--

Table D-4

DIFFUSION TEST SAMPLE DATA FOR TEST 4

Test No. 4 Type: Lapse Time of Day: 1516-1528 11 March 1964

Source: Uranine Source Quantity: 200 grams in 4 liters of water

Air-Sample-Filter Data

Station No.	Radial (deg)	Arc A, 88m Flow Rate (cfm)	Arc A, 88m Fluor Rdg (μa)	Arc A, 88m Sample Wt (10^{-8}gm)	Arc B, 176m Flow Rate (cfm)	Arc B, 176m Fluor Rdg (μa)	Arc B, 176m Sample Wt (10^{-8}gm)	Arc C, 352m Flow Rate (cfm)	Arc C, 352m Fluor Rdg (μa)	Arc C, 352m Sample Wt (10^{-8}gm)	Arc D, 704m Flow Rate (cfm)	Arc D, 704m Fluor Rdg (μa)	Arc D, 704m Sample Wt (10^{-8}gm)
1	330	0.60	2.1	5.2	0.60	2.2	5.6	0.60	1.2	1.0	--	--	--
2	332	0.60	4.9	15.5	0.60	2.4	6.6	0.60	--	--	--	--	--
3	334	0.60	6.9	24.5	0.60	2.6	7.4	0.60	1.0	--	--	--	--
4	336	0.60	23.0	82.0	0.60	2.0	4.8	0.60	1.2	1.0	--	--	--
5	338	0.60	22.0	78.0	0.60	3.1	9.4	0.60	1.1	--	0.60	1.1	--
6	340	0.60	16.0	52.0	0.60	2.3	6.2	0.60	1.2	1.0	0.60	1.0	--
7	342	0.60	23.0	82.0	0.60	2.0	4.8	0.60	1.4	2.2	0.60	1.0	--
8	344	0.60	18.0	64.0	0.60	1.8	4.0	0.60	1.5	2.6	0.60	1.0	--
9	346	0.60	27.0	96.0	0.60	1.8	4.0	0.60	1.8	4.0	0.60	1.0	--
10	348	0.60	32.0	115.0	0.60	2.7	7.8	0.60	1.0	--	0.60	1.0	--
11	350	0.60	56.0	205.0	0.60	2.3	6.3	0.60	2.6	7.4	0.60	1.2	1.0
12	352	0.60	58.0	210.0	0.60	1.7	3.5	0.60	4.6	15.5	0.60	1.4	2.2

Table D-4 (Cont'd)

Air-Sample-Filter Data

Station No.	Radial (deg)	Arc A, 88m Flow Rate (cfm)	Arc A, 88m Fluor Rdg (μa)	Arc A, 88m Sample Wt (10^{-8}gm)	Arc B, 176m Flow Rate (cfm)	Arc B, 176m Fluor Rdg (μa)	Arc B, 176m Sample Wt (10^{-8}gm)	Arc C, 352m Flow Rate (cfm)	Arc C, 352m Fluor Rdg (μa)	Arc C, 352m Sample Wt (10^{-8}gm)	Arc D, 704m Flow Rate (cfm)	Arc D, 704m Fluor Rdg (μa)	Arc D, 704m Sample Wt (10^{-8}gm)
13	354	0.60	58.0	210.0	0.60	2.6	7.4	0.60	2.1	5.4	0.60	1.1	--
14	356	0.60	62.0	230.0	0.60	3.8	12.5	0.60	3.0	7.0	0.60	1.0	--
15	358	0.60	45.0	165.0	0.60	9.4	33.0	0.60	1.9	4.4	0.60	1.0	--
16	360	0.60	61.0	225.0	0.60	15.0	52.0	0.60	1.3	1.6	0.60	1.0	--
17	002	0.60	27.0	96.0	0.60	27.0	96.0	0.60	1.0	--	0.60	1.0	--
18	004	0.60	24.0	95.0	0.60	5.6	19.5	0.60	1.4	2.2	0.60	--	--
19	006	0.60	33.0	120.0	0.60	3.9	12.5	0.60	1.1	--	0.60	--	--
20	008	0.60	15.0	52.0	0.60	1.4	2.2	0.60	1.1	--	0.60	1.0	--
21	010	0.60	9.4	33.0	0.60	--	--	0.60	1.0	--	0.60	--	--
22	012	0.60	8.7	29.0	0.60	--	--	0.60	--	--	0.60	1.0	--
23	014	0.60	4.1	14.0	0.60	--	--	0.60	--	--	0.60	--	--
24	016	0.60	1.3	16.0	0.60	1.1	--	0.60	--	--	0.60	--	--
25	018	0.60	1.0	1.0	0.60	--	--	0.60	--	--	0.60	--	--
26	020	0.60	--	--	0.60	--	--	0.57	--	--	0.60	--	--
27	022	0.60	--	--	0.60	--	--	0.60	--	--	0.60	--	--
28	024	0.60	1.6	3.1	0.60	--	--	0.57	--	--	0.60	1.0	--
29	026	0.60	--	--	0.60	--	--	0.60	1.4	2.2	--	--	--
30	028	0.60	--	--	0.60	1.0	--	0.60	1.1	--	--	--	--
31	030	0.60	1.3	1.6	0.60	--	--	0.60	--	--	--	--	--

Table D-5

IMPACTOR SAMPLE DATA FOR TEST 1

Test No. 1 Type: Lapse Time of Day: 1553-1556 27 January 1964

Source: Uranine Source Quantity: 40 grams in 4 liters of water

Andersen Impactor Data

Location			Stage Readings											
			1		2		3		4		5		Filter	
Arc	Station No.	Flow Rate (cfm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)	Fluor Rdg (μa)	Sample Wt (10^{-8}gm)
A	9 T	0.58	1.3	1.5	1.1	--	1.4	2.2	1.9	4.4	2.5	7.0	1.1	--
A	9 B	0.58	1.2	1.0	1.1	--	1.2	1.0	1.1	--	1.3	1.5		
A	16 T	0.60	1.9	4.4	1.4	2.2	1.5	2.6	2.5	7.0	4.5	15.0	1.7	3.5
A	16 B	0.60	1.4	2.2	1.3	1.5	1.3	1.5	1.4	2.2	1.3	1.5		
A	23 T	0.60	3.0	9.0	3.4	10.5	2.5	7.0	1.7	3.5	1.8	4.0	1.0	--
B	9 T	0.60	1.3	1.5	1.2	1.0	2.7	7.8	1.4	2.2	1.2	1.0	1.3	1.5
B	9 B	0.60	1.2	1.0	1.2	1.0	3.6	11.5	1.1	--	1.8	4.0		
B	16 T	0.60	1.2	1.0	1.2	1.0	1.3	1.5	1.6	3.0	1.9	4.4	1.0	--
B	16 B	0.60	1.2	1.0	1.1	--	1.1	--	1.2	1.0	1.2	1.0		
B	23 T	0.60	1.3	1.5	1.2	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.0	--
B	23 B	0.60	1.1	--	1.2	1.0	1.1	--	1.1	--	1.1	--		

Casella Impactor Data

A	5	0.25	1.7	--	1.0	--	1.0	--	1.0	--			1.0	--
A	13	0.60	1.7	3.5	1.4	2.2	1.4	2.2	2.0	4.8			7.6	26.5
A	18	0.46	1.2	1.0	1.3	1.5	1.8	4.0	1.0	--			1.3	1.5
B	5	0.51	1.0	--	1.0	--	1.0	--	1.0	--			1.0	--
B	13	0.29	1.0	--	1.0	--	1.0	--	1.0	--			1.3	1.5
B	19	0.25	1.0	--	1.0	--	1.0	--	1.0	--			1.0	--

Table D-6

IMPACTOR SAMPLE DATA FOR TEST 3

Test No. 3 Type: Lapse Time of Day: 0930-0946 21 February 1964

Source: Uranine Source Quantity: 200 grams in 4 liters of water

Andersen Impactor Data

Location			Stage Readings											
			1		2		3		4		5		Filter	
Arc	Station No.	Flow Rate (cfm)	Fluor Rdg (μa)	Sample Wt $(10^{-8}$gm)	Fluor Rdg (μa)	Sample Wt $(10^{-8}$gm)	Fluor Rdg (μa)	Sample Wt $(10^{-8}$gm)	Fluor Rdg (μa)	Sample Wt $(10^{-8}$gm)	Fluor Rdg (μa)	Sample Wt $(10^{-8}$gm)	Fluor Rdg (μa)	Sample Wt $(10^{-8}$gm
A	9	0.60	1.3	1.6	1.4	2.2	1.3	1.6	1.3	1.6	1.3	1.6	1.1	--
	16	0.60	3.2	9.9	4.4	14.5	9.4	32.5	7.2	25.0	6.0	21.0	1.2	1.0
	22	0.60	1.5	2.6	1.5	2.6	2.0	4.8	2.6	7.4	3.2	9.8	1.4	2.2
B	9	0.60	1.2	1.0	1.1	--	1.1	--	1.1	--	1.1	--	1.0	--
	16	0.60	1.2	1.0	1.2	1.0	1.1	--	1.2	1.0	1.1	--	1.1	--
	23	0.60	1.4	2.2	1.6	3.1	1.0	--	1.0	--	1.0	--	1.0	--

Casella Impactor Data

A	13	0.60	All less than 1.0		1.3	1.6
	18	0.60			2.1	5.2
B	5	0.58	All less than 1.0		1.0	--
	13	0.60			1.0	--

Table D-7

COMPARISON OF SAMPLING AT 5- AND 25-FT LEVELS ON ARC D

Station	Sample Weight (gm x 10^8)		25- to 5-ft Level Ratio
	5-ft Level	25-ft Level	
	Release 1 (Lapse), 40-gm source		
D-16	< 1.0	2.5	
D-17	< 1.0	1.0	1.75
D-18	< 1.0	< 1.0	
D-19	< 1.0	< 1.0	
	Release 2 (Lapse), 40-gm source		
D-16	< 1.0	< 1.0	
D-17	< 1.0	< 1.0	
D-18	< 1.0	< 1.0	
D-19	< 1.0	< 1.0	
	Release 3 (Lapse), 200-gm source		
D-16	2.2	1.0	
D-17	1.0	1.6	1.25
D-18	2.2	3.1	
D-19	2.2	4.0	
	Release 4 (Lapse), 200-gm source		
D-16	< 1.0	< 1.0	
D-17	< 1.0	< 1.0	
D-18	< 1.0	< 1.0	
D-19	< 1.0	< 1.0	

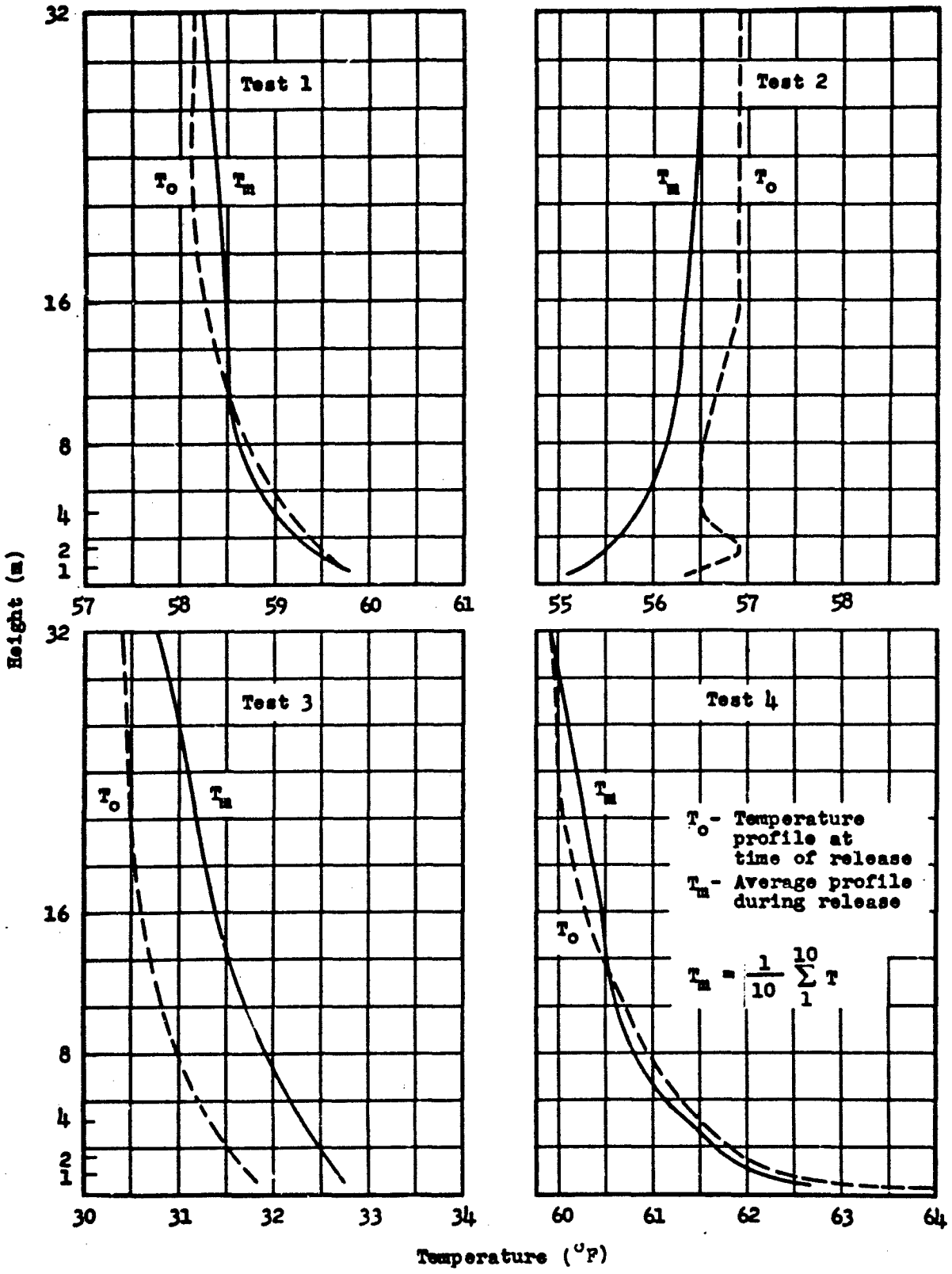
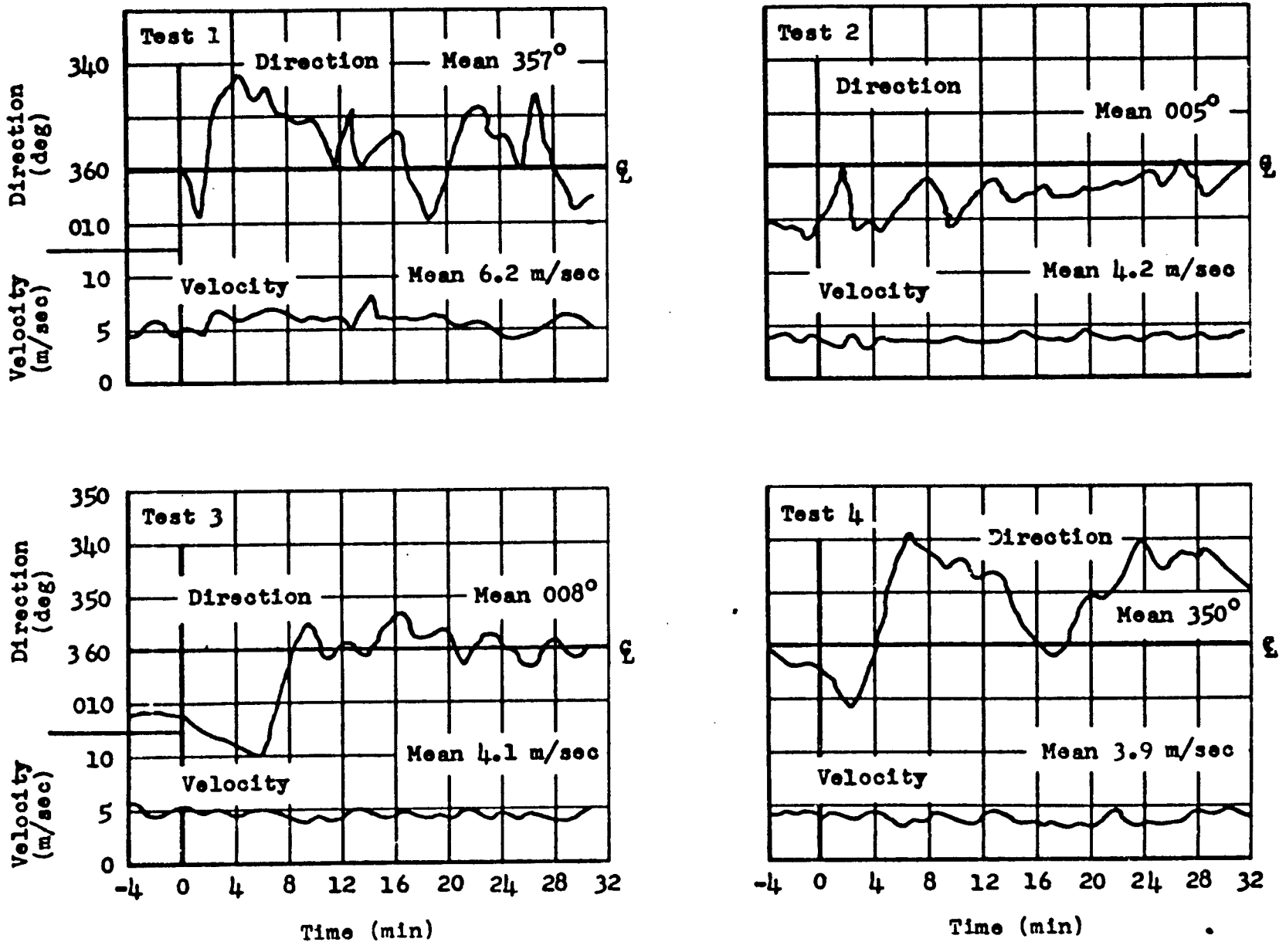


Figure D-1 Atmospheric Temperature Profiles during Tests 1 through 4


Test 1
Direction
Mean 357°
Direction (deg)
340
360
010
Velocity
Mean 6.2 m/sec
Velocity (m/sec)
10
5
0
Test 2
Direction
Mean 005°
Velocity
Mean 4.2 m/sec
Test 3
Direction
Mean 008°
350
340
350
360
010
Velocity
Mean 4.1 m/sec
10
5
0
-4 0 4 8 12 16 20 24 28 32
Time (min)
Test 4
Direction
Mean 350°
Velocity
Mean 3.9 m/sec
-4 0 4 8 12 16 20 24 28 32
Time (min)

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